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98005 (US). GOLDBERG, Howard, D.; 3007 Colony Crossing Drive. Sugar Land, TX 77479 (US). SCHMIDT, Martin, A.; 78 Ashley Place, Reading, MA 01867 (US). RIED, Robert, P.; 5010 Grove West Boulevard, No. 1602, Stafford, TX 77477-2622 (US).

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(74) Agent: MADAN, Paul, S.; Madan, Mossman & Sriram, P.C., Suite 700, 2603 Augusta, Houston, TX 77057 (US).

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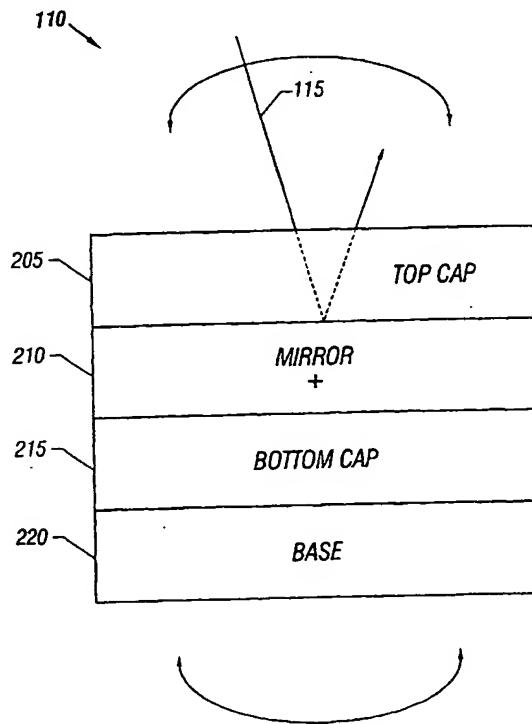
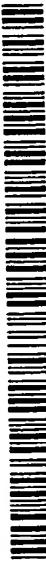
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(71) Applicant: INPUT OUTPUT, INC. (US/US); 12300 Charles E. Selecman Drive, Stafford, TX 77477 (US).

(72) Inventors: YU, Duli; 15700 Lexington Boulevard, No. 301, Sugar Land, TX 77478 (US). YU, Lianzhong; Apartment No. A-2, 13906 NE 9th PL, Bellevue, WA

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(54) Title: MICRO-MACHINED MIRROR DEVICE



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(57) Abstract: A micro machined mirror assembly is provided that includes a micro machined top cap (205), mirror (210), and bottom cap (215) mounted onto a ceramic substrate. The micro machined mirror is resiliently supported by a pair of T-shaped hinges and includes travel stops that limit motion of the mirror in the x-, y-, and z-directions. The top and bottom micro machined caps also include travel stops that limit motion of the mirror in the z-direction.



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## APPLICATION FOR PATENT

Title: MICRO-MACHINED MIRROR DEVICE

Background of the Invention

This invention relates generally to micro-machined three-dimensional structures, and in particular to micro-machined mirrors for use in optical readers, such as bar code readers or scanners.

5       Conventional bar code scanners are used to scan a surface with a laser beam. Conventional bar code scanners further typically utilize mirrors that are oscillated to permit the laser beam to scan. Conventional mirrors for bar code scanners are relatively large and imprecise.

In order to manufacture smaller and more precise bar code mirrors,  
10      micro-machining processes have been used in which a silicon substrate is micro-machined to produce a mirror. However, conventional micro-machined mirrors and their manufacturing processes suffer from a number of limitations. Prior art micro-machined mirrors do not provide appropriate compliance in all directions of the movement of the mirror. Such mirrors typically are not  
15      sufficiently shock resistant or able to operate over wide ranges of temperature over extended use.

The present invention provides micro-machined mirror devices which overcome one or more limitations of the existing micro-machined devices.

Summary of the Invention

According to one aspect of the present invention, a mirror assembly is provided that includes a mirror, a top cap, and a bottom cap. The mirror includes a mirror support structure, a pair of T-shaped hinges coupled to the mirror support structure and a mirrored plate coupled to the T-shaped hinges.

5 The mirrored plate includes one or more travel stops for limiting movement of the mirrored plate. The top cap is coupled to the top side of the mirror. The top cap includes a top cap support structure that includes an opening for permitting light to reflect off of the mirrored plate and one or more travel stops coupled to the top cap support structure for limiting movement of the mirrored

10 plate. The bottom cap is coupled to the bottom side of the mirror. The bottom cap includes a bottom cap support structure including an opening and one or more travel stops coupled to the bottom cap support structure for limiting movement of the mirrored plate.

15 According to another aspect of the present invention, a mirror assembly is provided that includes a support structure, pair of T-shaped hinges coupled to the support structure and a mirrored plate coupled to the T-shaped hinges. The mirrored plate includes one or more travel stops for limiting movement of the mirrored plate.

20 According to another aspect of the present invention, an apparatus is provided that includes a housing, a mass, and one or more springs for coupling the mass to the housing. Each spring includes a rotational spring constant and a translational spring constant. The rotational spring constant is decoupled from the translational spring constant.

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According to another aspect of the present invention, a method of resiliently supporting a mass in a housing is provided that includes coupling the mass to the housing using one or more hinges having translational spring constants and rotational spring constants and decoupling the translational spring constants from the rotational spring constants.

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According to another aspect of the present invention, a method of resiliently supporting a mass in a housing is provided that includes limiting translational movement of the mass in the X, Y and Z directions and limiting rotational or torsional movement of the mass.

According to another aspect of the present invention, an apparatus is provided that includes a housing and a mass resiliently coupled to the housing. The mass includes one or more travel stops for limiting rotational and translational or planar movement of the mass.

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According to another aspect of the present invention, a method of reflecting rays of light is provided that includes a reflective surface and providing an optical pathway for accessing the reflective surface or planar one or more cutouts for minimizing clipping of the incident and reflected light rays.

#### Brief Description of the Drawings

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**FIG. 1** is a cross section view of a laser scanning device according to the present invention.

**FIG. 2** is a schematic side view of a preferred embodiment of the mirror assembly of **FIG. 1**.

**FIG. 3** is a top view of the top cap of the mirror assembly of **FIG. 2**.

**FIG. 4** is a cross-sectional view of the top cap of **FIG.3**.

**FIG. 5** is a cross-sectional view of the top cap of **FIG. 3**.

**FIG. 6** is a top view of the mirror of the mirror assembly of **FIG. 2**.

**FIG. 6A** is a top view of an alternative embodiment of the hinge of the mirror assembly of **FIG. 2**.

5           **FIG. 6B** is a top view of an alternative embodiment of the hinge of the mirror assembly of **FIG. 2**.

**FIG. 6C** is a top view of an alternative embodiment of the hinge of the mirror assembly of **FIG. 2**.

10          **FIG. 6D** is a top view of an alternative embodiment of the mirror of the mirror assembly of **FIG. 2**.

**FIG. 7** is a cross-sectional view of the mirror of **FIG. 6**.

**FIG. 8** is a cross-sectional view of the mirror of **FIG. 6**.

**FIG. 9** is a bottom view of the mirror of **FIG. 6**.

**FIG. 10** is a top view of the bottom cap of the mirror assembly of **FIG.**

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**FIG. 11** is a cross-sectional view of the bottom cap of **FIG. 10**.

**FIG. 12** is a cross-sectional view of the bottom cap of **FIG. 10**.

**FIG. 13** is a top view of the base member of the mirror assembly of

**FIG. 2.**

20          **FIG. 14** is a cross-sectional view of the base member of **FIG. 13**.

**FIG. 15** is a cross-sectional view of the base member of **FIG. 13**.

**FIG. 16** is a top view of the top cap and mirror of the mirror assembly of **FIG. 2**.

**FIG. 17** is a top view of the bottom cap and base member of the mirror assembly of **FIG. 2**.

**FIG. 18** is a cross-sectional view of the mirror assembly of **FIG. 16** illustrating the oscillation of the mirror collection plate.

5       **FIG. 19** is a view of the mirror assembly of **FIG. 18** illustrating the use of tapered surfaces to minimize clipping of the laser light.

#### Detailed Description of the Preferred Embodiments

A mirror assembly for use in a bar code reader is provided. The mirror assembly preferably includes a micro-machined three-dimensional mirror supported generally by a pair of "T" shaped hinges in a support structure. 10 The mirror assembly further preferably includes one or more travel stops for limiting the movement of the mirror. The mirror assembly further preferably includes one or more tapered edge surfaces and cut-outs for minimizing clipping of incident and reflected laser beams.

15       **FIG. 1** is a cross section view of a laser scanning device such as a bar code scanner 100 having a light beam 115 that emanates from the device to strike a target 120. The light beam is reflected or scattered by the target 120. The bar code scanner 100 includes a laser beam source 105 and a mirror assembly 110. During the operation of the bar code scanner 100, the 20 optically reflective portion 111 of the mirror assembly 110 is preferably oscillated to permit the laser beam 115 to scan a surface, such as a bar code symbol 120, by reflecting the laser beam 115 off of the optically reflective portion 111 of the mirror assembly 110. The reflected light 125 enters the bar

code scanner 100 through a window 165 and is detected by a light detector 160. The laser beam source 105 may comprise any number of conventional commercially available devices to generate the laser beam 115.

The bar code scanner 100 may include additional features for user 5 interface, control and data processing. These features may comprise a processor 130 and memory device 135 as part of a central processing unit 140, a controller 145 for generating voltage used to oscillate the mirror 110, a data entry device such as a keypad 150 and a data display device such as a liquid crystal display 155. The mirror assembly 110 made according to the 10 present invention is described below in reference to FIGS. 2-19.

Referring to FIG. 2, in a preferred embodiment, the mirror assembly 110 includes a top cap 205, a mirror 210, a bottom cap 215, and a base member 220. The top cap 205 includes an opening that permits the laser beam 115 to reflect off of the mirror 210. In this manner, the mirror 210 is surrounded and protected by the top cap 205 and the bottom cap 215. The 15 sub-assembly that includes the top cap 205, mirror 210 and bottom cap 215 is formed and then mounted onto the base member 220.

The top cap 205 and bottom cap 215 may be fabricated from any 20 number of conventional commercially available materials such as, for example, silicon glass, ceramic or plastic. In a preferred embodiment, the top cap 205 is fabricated by micro-machining a silicon wafer.

FIGS. 3-5 show various views of a preferred embodiment of the top cap 205 which has a frame 301 that includes a top, bottom, left and right support members 305, 315, 325 and 335. Top and bottom travel stop

members 310 and 320 are coupled respectively to the top and bottom support members 305 and 315. The left and right support members 325 and 335 include corresponding left and right rim cutouts 330 and 340 for minimizing clipping of the incident light.

5       The top cap frame 301 provides an overall support structure for the top cap 205. The thickness of the frame 301 may range, for example, from about 400 to 600 microns with a preferred thickness ranging from about 390 to 400 microns in order to provide a compact structure having a low mass.

10      The top travel stop 310 preferably limits the motion of the reflective portion of the mirror 210 in the direction normal to the plane of the reflective portion of the mirror 210 (the Z-direction). The top travel stop 310 preferably extends in substantially orthogonal direction from the top support member 305. In a preferred embodiment, the top travel stop 310 is positioned within the plane of the top support member 305. The thickness of the top travel stop 310 may range, for example, from about 340 to 580 microns. In a preferred embodiment, the thickness of the top travel stop 310 ranges from about 350 to 380 microns in order to provide optimum shock protection, freedom of motion, and a compact structure having a low mass.

15      Referring to FIG. 4, in a particularly preferred embodiment, the bottom surface 310b of the top travel stop 310 is recessed below the level of the bottom surface 305b of the top support member 305. In this manner, the bottom surface 310b of the top travel stop 310 is preferably positioned above the level of the reflective surface of the mirror 210. The length of the top travel stop member 310 may range, for example, from about 800 to 2800

microns. In a preferred embodiment, the length of the top travel stop member 310 ranges from about 2000 to 2500 microns. In a particularly preferred embodiment, the length of the top travel stop member 310 is selected to overlap with the mirror collection plate 610 of the mirror by about 300

5 microns.

The bottom travel stop 320 extends in a substantially orthogonal direction from the bottom support member 315 and is substantially identical to the top travel stop 310. An opening 345 permits light to reflect off of the reflective surface of the mirror 210. The opening 345 preferably includes a left rim cut out 330 and a right rim cut out 340. The left and right rim cut outs, 330 and 340, are preferably positioned on opposite sides in surrounding relation to the reflective surface of the mirror 210. In this manner, the left and right rim cut-outs, 330 and 340, provide optical access to the reflective surface of the mirror 210.

15 In a preferred embodiment, the top cap frame 301, travel stops 310 and 320, rim cut outs 330 and 340, and the opening 345 all include tapered edges, 350A and 350B, to facilitate optical access to the reflective surface of the mirror 210 (FIG. 5). The taper angle of the tapered edges, 350A and 350B, preferably ranges from about 50 to 60 degrees in order to optimally facilitate the reflection of laser light transmitted at an angle towards the edge portions of the reflective surface of the mirror 210.

20 FIG. 6 shows a top view of a mirror or mirror assembly 210 made according to one embodiment of the present invention. The mirror 210 includes a frame or mirror support structure 600 having support members

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**602, 604, 606 and 608.** The mirror 210 further comprises a mirror collection plate 610 with a reflective surface 628, a top T-shaped hinge 612, a bottom T-shaped hinge 614, a top left travel stop finger 616, a top right travel stop finger 618, a bottom left travel stop finger 620, a bottom right travel stop finger 622, an opening 624, a conductive layer 626, and a reflective surface 628.

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The mirror frame 600 provides the overall support structure for the mirror 210. The thickness of the frame 600 may range, for example, from about 400 to 600 microns with a preferred thickness ranging from about 400 to 450 microns in order to provide a compact structure having a low mass. In a preferred embodiment, the support members 602, 604, 606, and 608 provide effective beam lengths ranging from about 500-2500 microns and cross sections of about 8,000 microns<sup>2</sup> to 160,000 microns<sup>2</sup> in order to optimally absorb shock loads of about 2000g/0.5 mS half sine wave input.

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The mirror collection plate 610 is coupled to the top T-shaped hinge 612 and the bottom T-shaped hinge 614. In this manner, the mirror collection plate 610 rotates about the axis 630 i.e. has torsional movement about such axis. In a preferred embodiment, the axis 630 is positioned substantially along the centerline of the mirror collection plate 610 and is coincident with the center of the T-shaped hinges, 612 and 614, thereby providing a common axis of rotation for the springs. The reflective surface 628 is coupled to the top 632 of the mirror collection plate 610. In this manner, rotation of the mirror collection plate 610 about the axis 630 causes laser light from a stationary laser to reflect off of the reflective surface 628 in a plurality of directions.

The thickness of the mirror collection plate 610 may range, for example, from about 100 to 600 microns with a preferred thickness ranging from about 100 to 250 microns to provide a low mass and maximize the effective natural frequency of the mirror 210.

5           The reflective surface 628 may be comprised of any number of conventional commercially available optically reflective surfaces such as, for example, gold, silver or aluminum. In a preferred embodiment, the reflective surface 628 comprises gold in order to optimize the amount of optical energy that is reflected. In a preferred embodiment, the surface roughness of the  
10          reflective surface 628 is less than about 0.1 wavelengths of the reflected light in order to optimize the amount of optical energy that is reflected.

15          The FIGS. 7 and 8 show cross-sectional views of the mirror of FIG. 6 and FIG. 9 shows a bottom view of the mirror of FIG. 6. As illustrated in FIGS. 7-9, in a preferred embodiment, the bottom 634 of the mirror collection plate 610 includes a top travel stop 710, a bottom travel stop 715, and a cavity 720. The top travel stop 710 extends from the bottom 634 of the mirror collection plate 610. The top travel stop 710 preferably limits movement of the mirror collection plate 610 in the z-direction. The top travel stop 710 preferably extends from the bottom 634 of the mirror collection  
20          plate 610 in a substantially orthogonal direction. The top travel stop 710 may extend from the bottom 634 of the mirror collection plate 610 for a distance ranging, for example, from about 200 to 400 microns with a preferred distance ranging from about 200 to 250 microns to optimally limit movement of the mirror collection plate 610. In a preferred embodiment, the top travel

stop 710 is centered about the axis 630 and is positioned adjacent to and on one side of the cavity 720. The bottom travel stop 715 is preferably identical to the top travel stop 710 described above.

The cavity 720 extends into the bottom of the mirror collection plate 610, which reduces the mass of the mirror collection plate 610. In this manner, the droop of the mirror 210 is reduced. In a preferred embodiment, the depth and volume of the cavity 720 ranges from about 200 to 500 microns and  $8 \times 10^6$  to  $1 \times 10^9$  microns.<sup>3</sup> In a preferred embodiment, the cavity 720 is centrally positioned along the axis 630 and within the back side 10 634 of the mirror collection plate 610.

For typical bar code scanner applications, the rotational accuracy of the laser beam may be required to be within 1.3° when the mirror collection plate 610 is subjected to an across-the-hinge self-induced gravity torque. Where torque  $T = mg \cdot h/2$ , with  $mg$  = mirror collection plate weight and  $h$  = 15 mirror collection plate thickness. The mirror accuracy is a function of the pointing accuracy and mirror droop. The torsional spring constant  $K_r$  of the T-shaped hinges, 612 and 614, is determined by the resonant frequency  $F$  of the mirror collection plate 610 and the size and mass of the mirror collection plate 610. The mirror tilt angle  $\theta$  due to a gravity torque is determined by the relation,  $\theta = T/K_r$ . Consequently, the thickness and mass of the mirror 20 collection plate 610, are preferably selected to provide a mirror tilt angle less than 1.3°. In a preferred embodiment, the thickness and mass of the mirror collection plate 610 are reduced by reducing the thickness of the mirror

collection plate 610 and by providing one or more cavities in the mirror collection plate 610.

The top T-shaped hinge 612 is coupled to the left support member 606, the right support member 608, and the top portion of the mirror 5 collection plate 610. The top T-shaped hinge 612 preferably includes a vertical support member 644 (beam or leg) and a second or horizontal support member 646 (T-member). The horizontal support member 646 preferably is supported at opposite ends by the left support member 606 and the right support member 608. In a preferred embodiment, the horizontal 10 support member 646 is substantially orthogonal to both the left support member 606 and the right support member 608. The vertical support member 644 is coupled to the horizontal support member 646. In a preferred embodiment, the vertical support member 644 is substantially orthogonal to the horizontal support member 646. The vertical support member 644 is coupled to the mid-point of the horizontal support member 15 646. The vertical support member 644 is positioned along the axis 630. The length, width and thickness of the vertical support member 644 may range, for example, from about 100 to 2500 microns, 2 to 100 microns and 2 to 100 microns, respectively. In a preferred embodiment, the length, width and 20 thickness of the vertical support member 644 range from about 800 to 1000 microns, 8 to 15 microns and 8 to 15 microns, respectively. The torsional spring constant of the vertical support member 644 may range, for example, from about  $2 \times 10^9$  to  $10 \times 10^7$  lbf-ft/radian. In a preferred embodiment, the torsional spring constant of the vertical support member 644 ranges from

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about  $2 \times 10^{-8}$  to  $10 \times 10^{-8}$  lbf·ft/radian. The length, width and thickness of the horizontal support member 646 may range, for example, from about 500 to 4500 microns, 6 to 100 microns and 6 to 100 microns, respectively. In a preferred embodiment, the length, width and thickness of the horizontal support member 646 range from about 2200 to 2500 microns, 15 to 25 microns and 15 to 25 microns, respectively.

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The bottom T-shaped hinge 614 is coupled to the left support member 606, the right support member 608, and the bottom portion of the mirror collection plate 610. The bottom T-shaped hinge 614 has the same structure as the top T-shaped hinge 612.

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Other embodiments of a T-shaped hinge according to the present invention, as illustrated in FIGS. 6A-6C, provide enhanced sensitivity for sensing acceleration loading conditions. In FIG. 6A, a T-shaped hinge 612A includes a vertical support member 644A having a serpentine shape and a horizontal support member 646A having a substantially linear shape. In FIG. 6B, an alternative embodiment of a T-shaped hinge 612B includes a vertical support member 644B coupled to a horizontal support member 646B at location that is off-center. In FIG. 6C, one or both of the T-shaped hinges 612 and 614 are modified to include a T-shaped hinge 612C having a vertical support member 644C that intersects a horizontal support member 646C at an acute angle and is also coupled to the horizontal support member 646C at location that is off-center.

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The top left travel stop 616 extends from and is coupled to the top left portion of the mirror collection plate 610. The top left travel stop 616

preferably limits the motion of the mirror collection plate **610** in the x-direction. The top left travel stop **616** preferably is positioned in the plane of the mirror collection plate **610**. In a preferred embodiment, the top left travel stop **616** extends from the mirror collection plate **610** in a substantially orthogonal direction. The thickness of the top left travel stop **616** may range, 5 for example, from about 200 to 600 microns. In a preferred embodiment, the thickness of the top left travel stop **616** ranges from about 250 to 350 microns in order to optimally provide shock protection, and a resilient compact structure having a low mass. The length of the top left travel stop **616** may range, for example, from about 500 to 2000 microns. In a preferred 10 embodiment, the length of the top left travel stop **616** ranges from about 900 to 1100 microns. In a particularly preferred embodiment, the top surface of the top left travel stop **616** is planar with the top surface of the mirror collection plate **610**. In a particularly preferred embodiment, the bottom 15 surface of the top left travel stop **616** is planar with the bottom surface of the mirror collection plate **610**.

The top right and bottom left and right travel stops **618**, **620** and **622** are substantially identical to the top left travel stop **616**. These travel stops are positioned in corresponding locations about the mirror collection plate 20 **610**.

The travel stops, **616**, **618**, **620** and **622**, preferably provide overswing and x-axis shock protection for the mirror collection plate **610** during manufacturing and operation. In a preferred embodiment, the travel stops **616**, **618**, **620**, and **622** are formed as integral parts of the mirror collection

plate 610. In a preferred embodiment, the travel stops 616, 618, 620, and 622 provide effective beam lengths greater than about 500 microns and cross sections of about 40,000 microns<sup>2</sup> to 240,000 microns<sup>2</sup> in order to optimally absorb shock loads of about 2000g/0.5 mS half sine wave input.

5                 The opening 624 preferably permits the mirror collection plate 610 to rotate about the axis 630. The walls 636 of the opening 624 preferably limit movement of the mirror collection plate 610 in the x-direction and the y-directions. The opening 624 preferably includes a top section 638, a middle section 640, and a bottom section 642. The top section 638 of the opening 10 624 preferably contains the top T-shaped hinge 612 and the top left and right travel stops, 616 and 618. The middle section 640 of the opening 624 preferably contains the mirror collection plate 610. The bottom section 642 of the opening 624 preferably contains the bottom T-shaped hinge 614 and the bottom left and right travel stops, 620 and 622.

15                 The walls of the middle section 640 of the opening 624 may be spaced apart from the opposing edges of the mirror collection plate 610 by a distance ranging, for example, from about 30 to 150 microns. In a preferred embodiment, the walls of the middle section 640 of the opening 624 are spaced apart from the opposing edges of the mirror collection plate 610 by a 20 distance ranging from about 60 to 100 microns in order to optimally minimize movement of the mirror collection plate 610 in the x and y directions. In a preferred embodiment, the gap in the x-direction is different from the gap in the y-direction in order to optimally protect the mirror collection plate 610 from shocks. In a preferred embodiment, the gap between the mirror

collection plate 610 and the middle section 640 of the opening 624 provides a spacing in the y-direction ranging from about 15 to 45 microns and a spacing in the x-direction ranging from about 50 to 180 microns in order to optimally limit shock loads on the mirror collection plate 610.

5           The conductive layer 626 is preferably coupled to the outer periphery of the top surface of the mirror 210. The conductive surface 626 preferably provides a conductive electrical path. The conductive layer 626 may be fabricated from any number of conventional commercially available materials such as, for example, gold, aluminum, or silver. In a preferred embodiment, 10 the conductive layer 626 is fabricated from gold. In a preferred embodiment, the conductive layer 626 is bonded to the underlying substrate by an intermediate layer of titanium.

15           The mirror 210 may be fabricated from any number of conventional commercially available materials such as, for example, silicon, plated metal or plastic. In a preferred embodiment, the mirror 210 is fabricated by micro-machining a silicon wafer using any one, or combination, of the known micro-machining processes.

20           In a preferred embodiment, the released and free-standing mirror collection plate 610 is connected to the surrounding support frame, 600 by the T-shaped hinges, 612 and 614. In a preferred embodiment, the travel stop fingers, 616, 618, 620 and 622, provide overswing protection for the mirror collection plate 610. In a preferred embodiment, a 200-micron deep anisotropic deep reactive ion etching (DRIE) process is used to form very precise, narrow gaps for X-axis shock protection and Y-axis shock protection,

where the mirror collection plate 610 is preferably completely confined within the frame, 602, 604, 606 and 608, for X-axis and Y-axis translational or planar motion i.e. in the planes of the mirrored surface. Persons having ordinary skill in the art and the benefit of the present disclosure will recognize that the term DRIE refers to deep reactive ion etching of a substrate. In a preferred implementation, the DRIE process is provided substantially as disclosed in United States Patent Nos. 5,498,312 and 5,501,893, which are incorporated herein by reference. The T-shaped hinges, 612 and 614, preferably provide the collection plate 610 with optimal translational motion in X-axis and Y-axis directions, in which the mirror collection plate 610 is shock-stopped by the frame, 602, 604, 606 and 608, while also simultaneously maintaining low stress levels within the T-shaped hinges, 612 and 614, to avoid fracture. In a preferred embodiment, the T-shape hinges, 612 and 614, are relatively compliant in the X-axis and Y-axis directions, while they are sufficiently rigid for rotational motion about the axis 630 for establishing the resonant frequency of the mirror collection plate 610.

Thus, in a preferred embodiment of the present invention, the mirror collection plate 610 is supported and suspended by a pair of hinges 612 and 614. These hinges permit torsional movement or rotation of the mirror collection plate 610 about the common hinge axis 630 and movement of the mirror collection in each of the x, y and z direction. The gap or space 648 between the mirror plate 610 and the frame 601 in the y-direction permits movement of the mirror collection plate 610 in the y-direction while the spacing 611 between the stops 616, 618, 620 and 621 and the frame 601

permit movement in the x-direction. The gap 647 provides a hinge compliance in the y-direction. The movements in the x and y directions are sometimes referred to the planar or translational movements and the hinges as springs. The beams 644 and 628 also permit the mirror collection plate 5 610 to move in the z-direction. The T-hinges provide the necessary compliance to the mirror collection plate motion in the y-direction, which improves the shock tolerance of the hinge to y-axis shock loads generated by the mirror collection plate 610. Prior art typically utilizes a straight-beam hinge, i.e. a beam connected to the frame without a T-member, such as the member 646. Such straight-beam hinges tend to buckle and fracture due to 10 y-axis shock loads. Also, the beams or legs 644 and 648 of the T-hinges 612 and 614 move up in the z-direction due to shock loads. The members 646 and 650 can torsionally rotate, which reduces the stress induced in the 644 and 648 members of the hinges, which stress has been found to be less 15 than the stress induced in the straight-beam hinges. The amount of stress reduction is a function of the "aspect ratio" of the hinges 612 and 614, which is a ratio of the width/thickness.

As illustrated in FIGS. 7-9, the mirror 210 preferably includes portions, 20 602, 604, 606 and 608, that are full-wafer thickness (e.g., 400 microns), and portions, 610, that are half-wafer thickness (e.g., 200 microns). The cavity 720 in the center of the mirror collection plate 610 is preferably etched 150-microns down from the bottom surface 634 of the mirror collection plate 610, and the T-shape hinges, 612 and 614, are preferably about 8-15 microns thick. The half-thickness mirror collection plate 610 reduces the amount of

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deep reactive ion etching (DRIE) and also improves the position accuracy of the mirror collection plate 610. The cavity 720, preferably etched in the center of the mirror collection plate 610, is preferably primarily used to improve the position accuracy of the mirror collection plate 610 and reduce the mass of the mirror collection plate 610 without substantially altering the resonant frequency.

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The backside of the mirror collection plate 610 preferably includes the Z travel-stops, 710 and 715, that preferably are full-wafer thickness (e.g., 400-microns). Since the mirror collection plate 610, is preferably 200-microns thick, the thicker travel-stops, 710 and 715, optimally maintain the 50-micron gap with the travel-stop fingers, 1010 and 1020, of the bottom cap 215 and, therefore, help provide shock protection in the Z-direction. A mirror collection plate 610 having minimum x-y plane dimensions of about 3-mm x 3-mm is preferred.

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In an alternative embodiment, as illustrated in FIG. 6D, the left and right support members, 606 and 608, of the mirror 210 further include cut-outs, 660A and 660B, positioned on opposite sides of the mirror collection plate 610. In this manner, the amount of viscous damping due to the resistance to the passage of air between the mirror collection plate 610 and the left and right support members, 606 and 608, is reduced. In this manner, the frequency response characteristics of the mirror 210 are enhanced.

As illustrated in FIGS. 10-12, the bottom cap 215 includes a bottom cap frame 1000 to provide support for the bottom cap. The frame 1000 includes support members and top and bottom travel stop members as

described above for the top cap and shown in FIG. 3. The bottom cap further comprises an upper left beam 1035, an upper right beam 1040, a lower left beam 1045, a lower right beam 1050, a top conductive surface 1055, a bottom conductive surface 1060, and an opening 1065.

5           The thickness of the bottom cap frame 1000 may range, for example, from about 400 to 600 microns with preferred thickness ranging from about 400 to 450 microns to provide a compact structure having a low mass.

The top travel stop member 1010 preferably limits the motion of the reflective portion of the mirror 210 in the z-direction. The top travel stop member 1010 preferably extends in a substantially orthogonal direction from the top support member 1005. In a preferred embodiment, the top travel stop member 1010 is positioned within the plane of the top support member 1005. The thickness of the top travel stop member 1010 may range, for example, from about 350 to 550 microns. In a preferred embodiment, the thickness of the top travel stop 1010 ranges from about 350 to 380 microns in order to provide a compact structure having a low mass. In a particularly preferred embodiment, the top surface 1010A of the top travel stop member 1010 is recessed below the level of the top surface 1005A of the top support member 1005. In this manner, the top surface 1010A of the top travel stop 1010 is preferably positioned below the level of the mirror collection plate 610 of the mirror 210. The length of the top travel stop member 1010 may range, for example, from about 1200 to 2800 microns. In a preferred embodiment, the length of the top travel stop member 1010 ranges from about 2000 to 2500 microns. In a particularly preferred embodiment, the

length of the top travel stop member 1010 is selected to overlap with the mirror collection plate 610 of the mirror by about 300 microns.

The bottom travel stop member 1020 preferably extends in a substantially orthogonal direction from the bottom support member 1015.

5       The bottom travel stop member 1020 is otherwise substantially identical to the above-described top travel stop member 1010.

The upper left beam 1035 preferably provides support and limits the motion of the mirror collection plate 610 of the mirror 210 in the z-direction during the manufacturing process. In this manner, defective mirrors 210 are 10 protected from shock, catastrophic failure and from falling into the process equipment during the manufacturing process. The upper left beam 1035 preferably extends in a substantially orthogonal direction from the left support member 1025. In a preferred embodiment, the upper left beam 1035 is positioned within the plane of the left support member 1025. The thickness 15 of the upper left beam 1035 may range, for example, from about 150 to 250 microns. In a preferred embodiment, the thickness of the upper left beam 1035 ranges from about 200 to 220 microns in order to optimally provide a compact structure having a low mass. In a particularly preferred embodiment, the top surface of the upper left beam 1035 is recessed below 20 the level of the top surface 1025A of the left support member 1025. In this manner, the top surface of the upper left beam 1035 is preferably positioned below the level of the top left travel stop member 616 of the mirror 210. The length of the upper left beam 1035 may range, for example, from about 1500

to 2200 microns. In a preferred embodiment, the length of the upper-left beam **1035** is about 1800 microns.

The upper right and lower left and right beams **1040**, **1045** and **1050** are substantially identical to the upper left beam **1035**. These beams are  
5 positioned within the plane of corresponding support members.

The top conductive surface **1055** is preferably coupled to the outer periphery of the top surface of the bottom cap **215**. The top conductive surface **1055** preferably provides a conductive electrical path. The top conductive surface **1055** further preferably provides a bonding ring for  
10 subsequent compression bonding of the bottom cap **215** to the mirror **210**.

The top conductive surface **1055** may be fabricated from any number of conventional commercially available materials such as, for example, gold, aluminum, or silver. In a preferred embodiment, the top conductive surface **1055** is fabricated from gold. In a preferred embodiment, the top conductive surface **1055** is bonded to the bottom cap **215** using an intermediate layer of  
15 titanium. The bottom conductive surface **1060** is preferably coupled to the outer periphery of the bottom surface of the bottom cap **215** and is otherwise substantially identical to the top conductive surface **1055**.

In a preferred embodiment, the conductive surfaces **1055** and **1060**  
20 conformally coat all of the exposed surfaces of the bottom cap **215**.

The opening **1065** preferably permits the drive pad electrodes, **1310** and **1315**, of the base member **220** to electrostatically drive and capacitatively sense the position of the mirror collection plate **610** of the mirror **210**. The opening **1065** preferably comprises a substantially

rectangular opening of greater size than the mirror collection plate 610 of the mirror 210.

As illustrated in FIGS. 13-15, in a preferred embodiment, the base member 220 includes a bottom plate 1305, a left drive pad electrode 1310, a right drive pad electrode 1315, a frame 1300, a conductive layer 1340, and conductive paths 1345, 1350 and 1355.

The bottom plate 1305, and frame 1300 together provide structural support for the base member 220. The base member 220 preferably supports the bottom cap 215, mirror 210 and the top cap 205.

10 The bottom plate 1305 preferably comprises a solid member fabricated from any number of conventional commercially available materials such as, for example, ceramic, silicon or glass. In a preferred embodiment, the thickness of the bottom plate 1305 ranges from about 200 to 400 microns.

15 The left drive pad electrode 1310 is coupled to the bottom plate 1305. The left drive pad electrode 1310 preferably permits the mirror collection plate 610 of the mirror 210 to be driven using electrostatic force and/or the position of the mirror collection plate 610 of the mirror 210 to be capacitively sensed. In this manner, the mirror collection plate 610 of the mirror 210 oscillates about the axis 630. In a preferred embodiment, the left drive pad electrode 1310 includes a conductive layer 1310A that is coupled to the conductive path 1350. In this manner, an electrical connection can be provided to the conductive layer 1310A. The conductive layer 1310A may be fabricated from any number of conventional commercially available materials

such as, for example, metal, polysilicon or conductive epoxy. In a preferred embodiment, the conductive layer 1310A is fabricated from metal.

The left drive pad electrode 1310 may have a top surface area ranging, for example, from about  $3 \times 10^6$  to  $10 \times 10^6$  microns.<sup>2</sup> In a preferred embodiment, the top surface area of the left drive pad electrode 1310 is about  $4.5 \times 10^6$  microns<sup>2</sup> in order to optimally drive the mirror collection plate 610 of the mirror 210. The left drive pad electrode 1310 preferably extends from the bottom plate 1305 in a substantially orthogonal direction. The left drive pad electrode 1310 may extend from the bottom plate 1305 for a distance ranging, for example, from about 50 to 200 microns. In a preferred embodiment, the left drive pad electrode 1310 extends from the bottom plate 1305 for a distance ranging from about 50 to 100 microns. In a particularly preferred embodiment, gap between the top of the left drive pad electrode 1310 and the bottom of the mirror collection plate 610 of the mirror 210 ranges from about 300 to 400 microns.

The right drive pad electrode 1315 is substantially identical to the left pad electrode 1310. In a preferred embodiment, the left and right drive pad electrodes, 1310 and 1315, are positioned substantially equidistant from the axis 630.

The top support member 1320 is coupled to the bottom plate 1305, the left support member 1330, the right support member 1335 and the conductive layer 1340. The top support member 1320 may have a length, width and height ranging, for example, from about 4000 to 6000 microns, 400 to 600 microns, and 400 to 600 microns. In a preferred embodiment,

the top support member **1320** length, width and height are about 4900 microns, 375 microns, and 400 microns.

The left support member **1330** is coupled to the bottom plate **1305**, the top support member **1320**, the bottom support member **1325** and the conductive layer **1340**. The left support member **1330** may have a length, width and height ranging, for example, from about 6000 to 9000 microns, 400 to 600 microns, and 400 to 600 microns. In a preferred embodiment, the left support member **1330** length, width and height are about 6800 microns, 375 microns, and 400 microns.

The bottom support member **1325** is substantially identical to the top support member **1320** and the right support member **1335** is substantially identical to the left support member **1330**.

In a preferred embodiment, the bottom plate **1305**, the top support member **1320**, the bottom support member **1325**, the left support member **1330**, and the right support member **1335** are integrally formed.

The conductive layer **1340** preferably extends around the periphery of the top surface of the base member **220**. The conductive layer **1340** preferably provides a conductive electric path for use in actuating the mirror collection plate **610** of the mirror **210**. The conductive layer **220** may be fabricated from any number of conventional commercially available materials such as, for example, metal, polysilicon or conductive epoxy. In a preferred embodiment, the conductive layer **1340** is fabricated from gold. The conductive layer **1340** may be coupled to the conductive path **1345** using conventional methods.

The base member 220 may be fabricated from any number of conventional commercially available materials such as, for example, ceramic, silicon or glass using any number of conventional fabrication processes.

5       The base 220 preferably provides electrode access to the mirror collection plate 610 for electrostatic actuation and capacitive position sensing using drive pad electrodes, 1310 and 1315. The design and operation of the electrostatic actuation and capacitative position sensing are well known in the art.

10      The metal ring 1340 around the perimeter of the base member 220, in combination with conductive-epoxy bonding of the base member 220 to the bottom cap 215, preferably provides electrical contact between the base member 220 and the bottom cap 215. In a preferred embodiment, the wafer bonding process preferably allows the bottom cap 215 to be in direct electrical contact with the mirror collection plate 610. Consequently, the 15     mirror collection plate 610 preferably can be electrically accessed, controlled, and monitored using the base member 220. The electrode drive pad and mirror contact metallization, 1310A, 1315A, and 1340, on the base member 220 are preferably connected to electrical contact pads on the backside of the base member 220, utilizing conventional thick-film through-hole via technology, which effectively makes the mirror assembly 110 a surface- 20    mount component.

Referring now to FIG. 16, a sub-assembly including the top cap 205 and the mirror 210 is illustrated. As illustrated in FIG. 16, the travel stops, 310 and 320, of the top cap 205 protect the mirror collection plate 610 from

z-axis shock while also minimizing the shadowing/overlapping of the reflective surface 628 of the mirror collection plate 610. Furthermore, the side rim cut-outs, 330 and 340, of the top cap 205 maximize the optical path to the reflective surface 628 of the mirror collection plate 610.

5 Referring now to FIG. 17, a sub-assembly including the bottom cap 215 and the base member 220 is illustrated. As illustrated in FIG. 17, the travel stop fingers, 1010 and 1020, protect the mirror collection plate 610 from z-axis shock while also maximizing the drive area of the drive pad electrodes, 1310 and 1315.

10 Referring now to FIG. 18, additional shock protection features of the mirror assembly 110 will be described. As illustrated in FIG. 18, preferably all of the interior walls of the top cap 205 and bottom cap 215 include tapered walls. In a preferred embodiment, the mirror collection plate 610 may be rotated out of plane by about 14° in both directions. In a preferred embodiment, the clearance between the mirror collection plate 610 and the interior walls of the top cap 205, bottom cap 215, and the support structure of the mirror 210 is about  $60 \pm 10$  microns for rotation ranging from -14° to 15 +14°. As also illustrated in FIG. 18, the travel stops, 320 and 1020, protect the mirror collection plate 610 from z-axis shocks. In a preferred embodiment, the clearance between the mirror collection plate 610 and the travel stops, 320 and 1020, is about 20-60 microns.

20 The travel stop fingers' 310 and 320 dimensions are chosen to make them sufficiently compliant in the z-direction to dissipate the Z-axis shock impact energy of the mirror hitting (urging) the travel-stop fingers. This

compliance provides a shock energy dissipation factor (not comprehended in the prior art) makes the resulting mirror assembly more robust to shock loads. The travel-stop fingers 616, 618, 620, and 626 are similarly made to have sufficient compliance in the x-direction to dissipate X-axis shock impact of the mirror plate hitting frame 600.

As illustrated in FIG. 18, the travel-stop fingers, 310 and 320, of the top cap 205 protect the mirror 210 from Z-axis shock while minimizing the shadowing/overlap of the mirror collection plate 610, thus providing the external laser optical access to the micromirror. The travel-stop fingers, 310 and 320, are preferably recessed about 20-60 microns from the surfaces of the top cap 205, which preferably sets the gap between the mirror collection plate 610 and the travel-stop fingers, 310 and 320, to be about 20-60 microns in the Z-direction. The tapered walls around the inside perimeter of the top cap 205 are preferably for capturing the mirror collection plate 610 during an input shock while the mirror collection plate 610 is rotated out-of-plane. The left and right rim cut-outs, 330 and 340, in the top cap 205 preferably provide clipping reduction. The travel-stop fingers, 1010 and 1020, of the bottom cap 215 preferably protect the mirror collection plate 610 from Z-axis shock while maximizing the area of the drive pad electrodes, 1310 and 1315. The travel-stop finger arrangement of the top and bottom caps, 205 and 215, preferably constrain the mirror collection plate 610 from Z-axis translational motion, while promoting torsional rotation of the mirror collection plate 610 about the axis 630. The bottom cap 215 also preferably

includes the beams, 1025, 1040, 1045, and 1050, for facilitating the handling of defective mirrors during the fabrication process.

As illustrated in FIGS. 6, 6A, 6B and 6C, the design of the T-shaped hinges 612 and 614, decouples the rotational spring constants from the 5 translational spring constants. In this manner, the mirror collection plate 610 is optimally protected from vibration and shock loads.

Referring now to FIG. 19, additional features of the mirror assembly 110 for optimizing the reflection of incident laser beams will be described. In an exemplary application of the sensor assembly 110, an incident laser beam A is directed to the mirror collection plate 610 at an angle of 45° and results in the reflected beam B. For a scanning range of  $\pm 10^\circ$ , the reflected laser beams are bound by the rays B' and B . In order to avoid laser beam clipping, the tapered walls and rim cut-outs, 330 and 340, of the top cap 205 minimize clipping of the incident and reflected laser beams. These features 10 are particularly advantageous in the situation where the incident laser beam is displaced resulting in the incident laser beam A' or the reflected laser beam B .  
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As illustrated in FIGS. 18 and 19, the tapered walls of the bottom cap 215 provide optimal shock protection to the mirror collection plate 610, and the tapered walls of the top cap 205 minimize clipping of the incident and reflected laser beams. The rim cut-outs, 330 and 340, of the top cap 205 further minimize shadowing and clipping of the incident and reflected laser 20 beams.

A mirror assembly has been described that includes a mirror, a top cap and a bottom cap. The mirror includes a mirror support structure, a pair of T-shaped hinges coupled to the mirror support structure and a mirrored plate coupled to the T-shaped hinges. The mirrored plate includes one or 5 more travel stops for limiting movement of the mirrored plate. The top cap is coupled to one side of the mirror. The top cap includes a top cap support structure including an opening for permitting light to reflect off of the mirrored plate and one or more travel stops coupled to the top cap support structure for limiting movement of the mirrored plate. The bottom cap is coupled to 10 another side of the mirror. The bottom cap includes a bottom cap support structure including an opening and one or more travel stops coupled to the bottom cap support structure for limiting movement of the mirrored plate. In a preferred embodiment, the mirror support structure includes a top support member, a bottom support member, a right side support member and a left 15 side support member. In a preferred embodiment, the mirror support structure includes an opening. In a preferred embodiment, the support structure opening includes a pair of oppositely positioned cut-outs. In a preferred embodiment, the support structure opening is complementary shaped with respect to the mirrored plate. In a preferred embodiment, the spacing between the edges of the support structure opening and the 20 mirrored plate ranges from about 15 to 180 microns. In a preferred embodiment, the pair of T-shaped hinges include a top T-shaped hinge and a bottom T-shaped hinge positioned in opposing relation to the top T-shaped hinge. In a preferred embodiment, the mirrored plate includes a plate

member including a first side and a second side, a reflective surface coupled to the first side of the plate member, a cavity formed in the second side of the plate member and a pair of travel stops coupled to the second side of the plate member. In a preferred embodiment, the plate member cavity includes a V-shaped cross section. In a preferred embodiment, the mirrored plate includes a plate member and one or more travel stops extending from the plate member. In a preferred embodiment, the travel stops are positioned in the plane of the plate member. In a preferred embodiment, the plate member travel stops that are positioned in the plane of the plate member have a length and thickness ranging from about 500 to 2000 microns and 200 to 600 microns. In a preferred embodiment, the plate member extend from the plane of the plate member. In a preferred embodiment, the plate member travel stops that extend from the plane of the plate member have a length ranging from about 200 to 250 microns. In a preferred embodiment, 15 the mirrored plate includes a plate member and a plurality of travel stops extending from the plate member. In a preferred embodiment, at least one of the plate member travel stops is positioned in the plane of the plate member and at least one of the travel stops extends from the plane of the plate member. In a preferred embodiment, each T-shaped hinge includes a first member and a second member coupled to the first member. In a preferred embodiment, the first and second members are substantially orthogonal. In a preferred embodiment, the length, width and thickness of the first hinge member ranges from about 500 to 4500 microns, 10 to 100 microns and 10 to 100 microns. In a preferred embodiment, the length,

width and thickness of the second hinge member ranges from about 400 to 1800 microns, 2 to 35 micron and 2 to 35 microns. In a preferred embodiment, each T-shaped hinge provides a torsional spring. In a preferred embodiment, the spring constant ranges from about  $2 \times 10^9$  to 5  $10 \times 10^7$  lbf-ft/radian. In a preferred embodiment, the top cap travel stops are positioned in the plane of the top cap support structure. In a preferred embodiment, the thickness of the top cap travel stops are less than the thickness of the top cap support structure. In a preferred embodiment, the opening in the top cap support structure includes a pair of oppositely positioned cut-outs. In a preferred embodiment, the cut-outs include tapered walls. In a preferred embodiment, the taper angle of the tapered walls ranges from about 55 to 60 degrees. In a preferred embodiment, the top cap opening includes tapered walls. In a preferred embodiment, the taper angle of the tapered walls ranges from about 55 to 60 degrees. In a preferred embodiment, the bottom cap travel stops are positioned in the plane of the bottom cap support structure. In a preferred embodiment, the thickness of the bottom cap travel stops are less than the thickness of the bottom cap support structure. In a preferred embodiment, the bottom cap opening includes tapered walls. In a preferred embodiment, the taper angle of the tapered walls ranges from about 55 to 60 degrees. In a preferred embodiment, the mirror assembly further includes a base member coupled to the bottom cap. In a preferred embodiment, the base member includes one or more drive pads for actuating the mirrored plate. In a preferred embodiment, the base member includes one or more sensing members for

sensing the position of the mirrored plate. In a preferred embodiment, the bottom cap further includes one or more support members for supporting the mirrored plate during the manufacturing process. In a preferred embodiment, the length and thickness of the top cap travel stops range from about 800 to 2800 microns and 340 to 580 microns. In a preferred embodiment, the length and thickness of the bottom cap travel stops range from about 800 to 2800 microns and 340 to 580 microns. In a preferred embodiment, one or more of the T-shaped hinges include a first member and a second member coupled to the first member, wherein the second member is perpendicular to the first member. In a preferred embodiment, one or more of the T-shaped hinges include a first member and a second member coupled to the first member, wherein the second member is serpentine. In a preferred embodiment, one or more of the T-shaped hinges include a first member and a second member coupled to the first member, wherein the second member is offset from the center of the first member. In a preferred embodiment, one or more of the T-shaped hinges include a first member and a second member coupled to the first member, wherein the second member intersects the first member at an acute angle. In a preferred embodiment, each T-shaped hinge includes a translational spring constant and a rotational spring constant that are decoupled from one another.

A mirror assembly has also been described that includes a support structure, a pair of T-shaped hinges coupled to the support structure and a mirrored plate coupled to the T-shaped hinges. The mirrored plate includes one or more travel stops for limiting movement of the mirrored plate. In a

preferred embodiment, each T-shaped hinge includes a rotational spring constant and a translational spring constant that are decoupled. In a preferred embodiment, the support structure includes a top support member, a bottom support member, a right side support member and a left side support member. In a preferred embodiment, the support structure includes an opening. In a preferred embodiment, the opening includes a pair of oppositely positioned cut-outs. In a preferred embodiment, the opening is complementary shaped with respect to the mirrored plate. In a preferred embodiment, the spacing between the edges of the opening and the mirrored plate ranges from about 15 to 180 microns. In a preferred embodiment, the pair of T-shaped hinges include a top T-shaped hinge and a bottom T-shaped hinge positioned in opposing relation to the top T-shaped hinge. In a preferred embodiment, the mirrored plate includes a plate member including a first side and a second side, a reflective surface coupled to the first side of the plate member, a cavity formed in the second side of the plate member and a pair of travel stops coupled to the second side of the plate member. In a preferred embodiment, the cavity includes a V-shaped cross section. In a preferred embodiment, the mirrored plate includes a plate member and one or more travel stops extending from the plate member. In a preferred embodiment, the travel stops are positioned in the plane of the plate member. In a preferred embodiment, the travel stops that are positioned in the plane of the plate member have a length and thickness that range from about 500 to 2000 microns and 200 to 600 microns. In a preferred embodiment, the travel stops extend from the plane of the plate

member. In a preferred embodiment, the travel stops that extend from the plane of the plate member have a length that extends from about 200 to 250 microns. In a preferred embodiment, the mirrored plate includes a plate member and a plurality of travel stops extending from the plate member. In 5 a preferred embodiment, at least one of the travel stops is positioned in the plane of the plate member and at least one of the travel stops extends from the plane of the plate member. In a preferred embodiment, each T-shaped hinge includes a first member and a second member coupled to the first member. In a preferred embodiment, the first and second members are substantially orthogonal. In a preferred embodiment, the length, width and thickness of the first member ranges from about 500 to 4500 microns, 10 to 100 microns and 10 to 100 microns. In a preferred embodiment, the length, width and thickness of the second member ranges from about 400 to 1800 microns, 20 to 35 microns and 2 to 35 microns. In a preferred embodiment, 10 each T-shaped hinge provides a torsional spring. In a preferred embodiment, the spring constant ranges from about  $2 \times 10^{-9}$  to  $10 \times 10^{-7}$  lbf-ft/radian. In a preferred embodiment, one or more of the T-shaped hinges include a first member and a second member coupled to the first member, wherein the second member is perpendicular to the first member. In a 15 preferred embodiment, one or more of the T-shaped hinges include a first member and a second member coupled to the first member, wherein the second member is serpentine. In a preferred embodiment, one or more of the T-shaped hinges include a first member and a second member coupled to the first member, wherein the second member is offset from the center of 20

the first member. In a preferred embodiment, one or more of the T-shaped hinges include a first member and a second member coupled to the first member, wherein the second member intersects the first member at an acute angle.

- 5 An apparatus has also been described that includes one or more T-shaped springs and a mass coupled to the T-shaped springs. In a preferred embodiment, the mass includes a reflective surface. In a preferred embodiment, the mass includes one or more travel stops for limiting movement of the mass. In a preferred embodiment, the apparatus further
- 10 includes a top cap coupled to the top of the mass, wherein the top cap includes one or more travel stops for limiting movement of the mass. In a preferred embodiment, the apparatus further includes a bottom cap coupled to bottom of the mass, wherein the bottom cap includes one or more travel stops for limiting movement of the mass. In a preferred embodiment, the
- 15 apparatus further includes a top cap coupled to the top of the mass and a bottom cap coupled to the bottom of the mass, wherein the top and bottom caps each include one or more travel stops for limiting movement of the mass. In a preferred embodiment, each T-shaped hinge includes a rotational spring constant and a translational spring constant that are decoupled. In a preferred embodiment, the apparatus comprises an
- 20 accelerometer. In a preferred embodiment, the apparatus comprises a gyroscope.

An apparatus also has been described that includes a housing, a mass, and one or more springs for coupling the mass to the housing. Each

spring includes a rotational spring constant and a translational spring constant. The rotational spring constant is decoupled from the translational spring constant. In a preferred embodiment, the springs are fabricated by a process including micromachining a substrate. In a preferred embodiment, the housing, mass and springs are fabricated by a process including micromachining a substrate. In a preferred embodiment, each spring comprises a plurality of springs. In a preferred embodiment, each spring is T-shaped. In a preferred embodiment, the apparatus further includes a top cap coupled to the top of the housing including a top cap cutout and a bottom cap coupled to the bottom of the housing including a bottom cap cutout. The top and bottom cap cutouts limit movement of the mass when the mass is rotated away from its rest position. In a preferred embodiment, each cutout includes tapered side walls. In a preferred embodiment, the tapered side walls are rotated from the vertical direction at an angle ranging from about 15 to 45 degrees.

A method of resiliently supporting a mass in a housing also has been described that includes coupling the mass to the housing using one or more springs having translational spring constants and rotational spring constants and decoupling the translational spring constants from the rotational spring constants. In a preferred embodiment, the springs are fabricated by a process including micromachining a substrate. In a preferred embodiment, the housing, mass and springs are fabricated by a process including micromachining a substrate. In a preferred embodiment, each spring comprises a plurality of springs. In a preferred embodiment, each spring is

T-shaped. In a preferred embodiment, method further includes limiting movement of the mass when it is rotated from a rest position. In a preferred embodiment, limiting movement of the mass when it is rotated from a rest position includes limiting translation of the mass when it is rotated from the  
5 rest position.

A method of resiliently supporting a mass in a housing also has been described that includes limiting translational movement of the mass in the X, Y and Z directions and limiting rotational movement of the mass. In a preferred embodiment, the housing and mass are fabricated by a process including micromachining a substrate. In a preferred embodiment, the method further includes limiting movement of the mass when it is rotated from a rest position. In a preferred embodiment, limiting movement of the mass when it is rotated from a rest position includes limiting translation of the mass when it is rotated from the rest position.  
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An apparatus also has been described that includes a housing and a mass resiliently coupled to the housing, the mass including one or more travel stops for limiting rotational and translational movement of the mass. In a preferred embodiment, the housing includes an opening for receiving the mass that limits the translational movement of the mass. In a preferred embodiment, the apparatus further includes a top cap coupled to the top of the housing and a bottom cap coupled to the bottom of the housing. The top and bottom caps limit movement of the mass when it is rotated out of its rest position within the housing. In a preferred embodiment, the top and bottom caps includes cutouts. In a preferred embodiment, each cutout includes  
20

tapered side walls. In a preferred embodiment, the tapered side walls are rotated from the vertical direction at an angle ranging from about 15 to 45 degrees.

An apparatus also has been described that includes a housing  
5 including an opening, the opening including one or more cutouts and a reflective surface resiliently coupled to the housing. In a preferred embodiment, each cutout includes tapered side walls. In a preferred embodiment, the tapered side walls are rotated from the vertical direction at an angle ranging from about 15 to 45 degrees. In a preferred embodiment,  
10 the housing and reflective surface are fabricated by a process including micromachining a substrate.

A method of reflecting rays of light also has been described that includes providing a reflective surface and providing an optical pathway for accessing the reflective surface including one or more cutouts for minimizing  
15 clipping of the incident and reflected light rays. In a preferred embodiment, the optical pathway includes sidewalls that are rotated from the vertical direction at an angle ranging from about 15 to 45 degrees. In a preferred embodiment, the optical pathway and reflective surface are fabricated by a process including micromachining a substrate.

20 Although illustrative embodiments of the invention have been shown and described, a wide range of modification, changes and substitution is contemplated in the foregoing disclosure. In some instances, some features of the present invention may be employed without a corresponding use of the other features. Accordingly, it is appropriate that the appended claims be

construed broadly and in a manner consistent with the scope of the invention.

CLAIMS

- 1        1. An apparatus for use in making optical measurements,  
2           comprising;
  - 3                (a) a mass having an exposed reflective surface;
  - 4                (b) a pair of hinges attached to a support structure supporting said  
5                mass, said hinges enabling the mass torsional movement about a  
6                common axis of the hinges, vertical movement (z-direction),  
7                movement along a first planar direction (x-direction) of the reflective  
8                surface and movement along a second planar direction (y-direction) of  
9                the reflective surface, wherein said vertical, first and second planar  
10          directions are orthogonal to each other.
- 1        2. The apparatus of claim 1, wherein said hinges are T-shaped  
2           with a first member (leg) attached to the mass and a second member (T-  
3           member) attached to the leg and to the support structure at opposite ends of  
4           the T-member, said T-member capable of moving in the y-direction, thereby  
5           providing compliancy to the mass in the y-direction.
- 1        3. The apparatus of claim 2 further comprising at least one x-  
2           travel stop limiting movement of the mass in the first planar direction.
- 1        4. The apparatus of claim 3 wherein the at least one x-travel stop  
2           includes a first member carried by the support structure and a second  
3           member carried by the mass.

1           5. The apparatus of claim 4 wherein the mass has a plurality of  
2       sides and wherein the at least one x-travel stop includes a separate travel  
3       stop corresponding to each said side of the mass.

1           6. The apparatus of claim 2 further comprising at least one y-  
2       travel stop limiting movement of the mass in the second planar direction.

1           7. The apparatus of claim 6 wherein at least one y-travel stop  
2       includes a member carried by the support structure that limits the movement  
3       of the mass in the second planar direction.

1           8. The apparatus of claim 6 wherein the mass has a plurality of  
2       sides and at least one y-travel stop includes a separate member carried by  
3       the support structure to limit movement of the mass along each said side of  
4       the mass.

1           9. The apparatus of claim 1 further comprising a first planar stop  
2       to limit movement of the mass in a first planar direction and a second planar  
3       stop to limit the movement of the mass in the second planar direction.

1           10. The apparatus of claim 9 wherein the first planar stop includes  
2       a first member carried by the support structure and a second member carried  
3       by the mass which cooperate with each other to limit travel of the mass in the

4           first planar direction and the second planar stop includes a member carried  
5           by the mass that limits travel of the mass in the second planar directions.

1           11.   The apparatus of claim 1 further comprising a vertical travel  
2           stop that limits the movement of the mass in a vertical direction is  
3           perpendicular to the exposed reflective surface.

1           12.   The apparatus of claim 11 wherein the vertical travel stop  
2           includes a separate finger member placed a predetermined distance from  
3           each said hinge, each said finger member having length greater than a  
4           planar dimensions of the hinges.

1           13.   The apparatus of claim 1 wherein the hinges permit torsional  
2           movement of the mass about a common axis of the hinges, said common  
3           axis in the y-direction.

1           14.   The apparatus of claim 1 wherein each said hinge has a  
2           predetermined torsional (rotational) spring constant and a translational spring  
3           constant wherein the torsional spring constant is decoupled from the  
4           translational spring constant.

1           15.   A mirror assembly, comprising:  
2               (a)   an enclosure having a top opening exposed to the  
3               environment;  
4               (b)   a mirror having a reflective planar surface; and

5                             (c)     a pair of hinges attached to said mirror and said support  
6     structure to suspend said mirror in the support structure with the reflective  
7     planar surface of the mirror exposed to the environment, said hinges allowing  
8     the mirror torsional movement about a common axis of the hinges, vertical  
9     movement, movement in a first planar directions and movement in a second  
10    planar direction.

1                             16.    The mirror assembly of claim 15 wherein the enclosure  
2     includes at least one of (i) a tapered upper side or (ii) a cut out to prevent  
3     clipping of a light beam striking said mirror at an angle.

1                             17.    The mirror assembly according to claim 15 or 16 wherein the  
2     support structure further includes a tapered section that limits movement of  
3     the mirror in a particular diagonal direction combination of z and x or z and y  
4     directions.

1                             18.    The mirror assembly according to claim 17 wherein the  
2     particular diagonal direction is a combination of one of the (i) z and x axis;  
3     and (ii) z and y axis.

1                             19.    The mirror assembly according to any of the claims 15-18  
2     wherein the enclosure includes substantially identical top and bottom caps,  
3     each said bottom and top cap including a travel stop that limits movement of  
4     the mirror in the vertical direction .

1               20. The mirror assembly according to claim 15 further comprising a  
2               bottom cap and top cap that includes a separate travel stop that limit  
3               diagonal movement of the mirror in a particular direction.

1               21. A mirror assembly, comprising:  
2                   a mirror including:  
3                   a mirror support structure;  
4                   a pair of T-shaped hinges coupled to the mirror support  
5                   structure; and  
6                   a mirrored plate coupled to the T-shaped hinges, the mirrored  
7                   plate including: one or more travel stops for limiting movement  
8                   of the mirrored plate; a top cap coupled to one side of the  
9                   mirror, the top cap including:  
10                  a top cap support structure including: an opening for permitting  
11                  light to reflect off of the mirrored plate; and  
12                  one or more travel stops coupled to the top cap support  
13                  structure for limiting movement of the mirrored plate; and a  
14                  bottom cap coupled to another side of the mirror, the bottom cap  
15                  including:  
16                  a bottom cap support structure including an opening; and  
17                  one or more travel stops coupled to the bottom cap support  
18                  structure for limiting movement of the mirrored plate.

1               22. The mirror assembly of claim 21, wherein each T-shaped hinge  
2               includes:

3                   a translational spring constant; and  
4                   a rotational spring constant;  
5                   wherein the translational spring constant is decoupled from the  
6                   rotational spring constant.

1                 23. The mirror assembly of claim 21, wherein the mirror support  
2                   structure comprises an opening that includes a pair of oppositely positioned  
3                   cut-outs.

1                 24. The mirror assembly of claim 23, wherein the spacing between  
2                   the edges of the opening and the mirrored plate ranges from about 60 to 100  
3                   microns.

1                 25. The mirror assembly of claim 21, wherein the pair of T-shaped  
2                   hinges include:

3                   a top T-shaped hinge; and  
4                   a bottom T-shaped hinge positioned in opposing relation to the  
5                   top T-shaped hinge.

1                 26. The mirror assembly of claim 21, wherein the mirrored plate  
2                   includes:  
3                   a plate member including a first side and a second side;  
4                   a reflective surface coupled to the first side of the plate member;  
5                   a cavity formed in the second side of the plate member; and

6                   a pair of travel stops coupled to the second side of the plate  
7                   member.

1                 27. The mirror assembly of claim 26, wherein the travel stops are  
2                 positioned in the plane of the plate member.

1                 28. The mirror assembly of claim 27, wherein the travel stops have  
2                 a length ranging from about 900 to 1100 microns.

1                 29. The mirror assembly of claim 26, wherein the travel stops have  
2                 a thickness ranging from about 250-350 microns.

1                 30. The mirror assembly of claim 21, wherein each T-shaped hinge  
2                 includes:  
3                   a first member; and  
4                   a second member coupled to the first member.

1                 31. The mirror assembly of claim 30, wherein the first and second  
2                 members are substantially orthogonal.

1                 32. The mirror assembly of claim 30, wherein the length and  
2                 diameter of the first member ranges from about 2200 to 2500 microns and 15  
3                 to 25 microns.

1           33. The mirror assembly of claim 30, wherein the length and  
2         diameter of the second member ranges from about 800 to 1000 microns and  
3         8 to 15 microns.

1           34. The mirror assembly of claim 21, wherein each T-shaped hinge  
2         provides a torsional spring constant.

1           35. The mirror assembly of claim 34, wherein the spring constant  
2         ranges from about  $2 \times 10^{-8}$  to  $10 \times 10^{-8}$  lbf/radian.

1           36. The mirror assembly of claim 21, wherein the top cap travel  
2         stops are positioned in the plane of the top cap support structure.

1           37. The mirror assembly of claim 21, wherein the thickness of the  
2         top cap travel stops are less than the thickness of the top cap support  
3         structure.

1           38. The mirror assembly of claim 21, wherein the opening in the top  
2         cap support structure includes a pair of oppositely positioned cut-outs.

1           39. The mirror assembly of claim 38, wherein the cut-outs include  
2         tapered walls.

1           40. The mirror assembly of claim 39, wherein the taper angle of the  
2         tapered walls ranges from about 50 to 60 degrees.

1           41. The mirror assembly of claim 21, wherein the top cap opening  
2 includes tapered walls.

1           42. The mirror assembly of claim 41, wherein the taper angle of the  
2 tapered walls ranges from about 50 to 60 degrees.

1           43. The mirror assembly of claim 21, wherein the bottom cap travel  
2 stops are positioned in the plane of the bottom cap support structure.

1           44. The mirror assembly of claim 21, wherein the thickness of the  
2 bottom cap travel stops are less than the thickness of the bottom cap support  
3 structure.

1           45. The mirror assembly of claim 21, wherein the bottom cap  
2 opening includes tapered walls.

1           46. The mirror assembly of claim 45, wherein the taper angle of the  
2 tapered walls ranges from about 50 to 60 degrees.

1           47. The mirror assembly of claim 21, further including a base  
2 member coupled to the bottom cap.

1           48. The mirror assembly of claim 47, wherein the base member  
2 includes one or more drive pads for actuating the mirrored plate.

1           49. The mirror assembly of claim 47, wherein the base member  
2 includes one or more sensing members for sensing the position of the  
3 mirrored plate.

1           50. The mirror assembly of claim 21, wherein the bottom cap further  
2 includes one or more support members for supporting the mirrored plate  
3 during the manufacturing process.

1           51. The mirror assembly of claim 21, wherein the length of the top  
2 cap travel stops ranges from about 2000 to 2500 microns.

1           52. The mirror assembly of claim 21, wherein the top cap travel  
2 stops have a thickness ranging from about 350 to 380 microns.

1           53. The mirror assembly of claim 21, wherein the length of the  
2 bottom cap travel stops ranges from about 2000 to 2500 microns.

1           54. The mirror assembly of claim 21, wherein the bottom cap travel  
2 stops have a thickness ranging from about 350 to 380 microns.

1           55. The mirror assembly of claim 21, wherein one or more of the  
2 T-shaped hinges include:  
3                 a first member; and  
4                 a second member coupled to the first member;

5                   wherein the second member is one of (i) serpentine, (ii) offset  
6                   from the center of the first member; and (iii) intersects the first member  
7                   at an acute angle.

1                 56. A method of resiliently supporting a mass in a housing,  
2                   comprising:  
3                   limiting translational movement of the mass in the X, Y and Z  
4                   directions; and  
5                   limiting rotational movement of the mass.

1                 57. The method of claim 56, wherein the housing and mass are  
2                   fabricated by a process including micro-machining a substrate.

1                 58. The method of claim 56, further including:  
2                   limiting movement of the mass when it is rotated from a rest  
3                   position.

1                 59. The method of claim 58, wherein limiting movement of the mass  
2                   when it is rotated from a rest position includes limiting translation of the  
3                   mass when it is rotated from the rest position.

1                 60. An apparatus, comprising:  
2                   a housing; and

3                   a mass resiliently coupled to the housing, the mass including  
4                   one or more travel stops for limiting rotational and translational  
5                   movement of the mass.

1                 61. The apparatus of claim 60, wherein the housing includes an  
2                   opening for receiving the mass; and wherein the opening limits the  
3                   translational movement of the mass.

1                 62. The apparatus of claim 60, further including:  
2                   a top cap coupled to the top of the housing; and  
3                   a bottom cap coupled to the bottom of the housing;  
4                   wherein the top and bottom caps limit movement of the mass  
5                   when it is rotated out of its rest position within the housing.

1                 63. The apparatus of claim 62, wherein the top and bottom caps  
2                   includes cutouts.

1                 64. The apparatus of claim 63, wherein each cutout includes  
2                   tapered side walls.

1                 65. The apparatus of claim 64, wherein the tapered side walls are  
2                   rotated from the vertical direction at an angle ranging from about 15 to  
3                   45 degrees.

- 1        66. An apparatus, comprising:
  - 2              a housing including an opening, the opening including one or
  - 3              more cutouts; and
  - 4              a reflective surface resiliently coupled to the housing.
- 1        67. The apparatus of claim 66, wherein each cutout includes  
2              tapered side walls.
- 1        68. The apparatus of claim 67, wherein the tapered side walls are  
2              rotated from the vertical direction at an angle ranging from about 15 to  
3              45 degrees.
- 1        69. The apparatus of claim 66, wherein the housing and reflective  
2              surface are fabricated by a process including micromachining a  
3              substrate.
- 1        70. A method of reflecting rays of light, comprising:
  - 2              providing a reflective surface; and
  - 3              providing an optical pathway for accessing the reflective surface
  - 4              including one or more cutouts for minimizing clipping of the
  - 5              incident and reflected light rays.
- 1        71. The method of claim 70, wherein the optical pathway includes  
2              sidewalls that are rotated from the vertical direction at an angle ranging  
3              from about 15 to 45 degrees.

1           72. The method of claim 70, wherein the optical pathway and  
2           reflective surface are fabricated by a process including micro-  
3           machining a substrate.

1           73. A mirror assembly, comprising:  
2                 a support structure;  
3                 a pair of T-shaped hinges coupled to the support structure; and  
4                 a mirrored plate coupled to the T-shaped hinges, the mirrored  
5                 plate  
6                 including:  
7                 one or more travel stops for limiting movement of the  
8                 mirrored plate.

1           74. The mirror assembly of claim 73, wherein each T-shaped hinge  
2           includes:  
3                 a translational spring constant; and  
4                 a rotational spring constant; wherein the translational spring  
5                 constant is decoupled from the rotational spring constant.

1           75. The mirror assembly of claim 73, wherein the mirror support  
2           structure includes:  
3                 a top support member;  
4                 a bottom support member;  
5                 a right side support member; and

6                   a left side support member.

1                 76.   The mirror assembly of claim 73, wherein the mirror support  
2                   structure includes an opening.

1                 77.   The mirror assembly of claim 76, wherein the opening includes  
2                   a pair of oppositely positioned cut-outs.

1                 78.   The mirror assembly of claim 76, wherein the opening is  
2                   complementary shaped with respect to the mirrored plate.

1                 79.   The mirror assembly of claim 78, wherein the spacing between  
2                   the edges of the opening and the mirrored plate ranges from about 60  
3                   to 100 microns.

1                 80.   The mirror assembly of claim 73, wherein the pair of T-shaped  
2                   hinges include:  
3                         a top T-shaped hinge; and  
4                         a bottom T-shaped hinge positioned in opposing relation to the  
5                         top T-shaped hinge.

1                 81.   The mirror assembly of claim 73, wherein the mirrored plate  
2                   includes:  
3                         a plate member including a first side and a second side;  
4                         a reflective surface coupled to the first side of the plate member;

5                   a cavity formed in the second side of the plate member; and  
6                   a pair of travel stops coupled to the second side of the plate  
7                   member.

1                 82.   The mirror assembly of claim 81, wherein the cavity includes a  
2                   V-shaped cross section.

1                 83.   The mirror assembly of claim 73, wherein the mirrored plate  
2                   includes:

3                   a plate member; and  
4                   one or more travel stops extending from the plate member.

1                 84.   The mirror assembly of claim 83, wherein the travel stops are  
2                   positioned in the plane of the plate member.

1                 85.   The mirror assembly of claim 84, wherein the travel stops have  
2                   a length ranging from about 900 to 1100 microns.

1                 86.   The mirror assembly of claim 83, wherein the travel stops have  
2                   a thickness ranging from about 250-350 microns.

1                 87.   The mirror assembly of claim 83, wherein the travel stops  
2                   extend from the plane of the plate member.

1           88. The mirror assembly of claim 87, wherein the travel stops have  
2           a length ranging from about 200 to 250 microns.

1           89. The mirror assembly of claim 73, wherein the mirrored plate  
2           includes:

3                 a plate member; and  
4                 a plurality of travel stops extending from the plate member.

1           90. The mirror assembly of claim 89, wherein at least one of the  
2           travel stops is positioned in the plane of the plate member and at least  
3           one of the travel stops extends from the plane of the plate member.

1           91. The mirror assembly of claim 73, wherein each T-shaped hinge  
2           includes:  
3                 a first member; and  
4                 a second member coupled to the first member.

1           92. The mirror assembly of claim 91, wherein the first and second  
2           members are substantially orthogonal.

1           93. The mirror assembly of claim 91, wherein the length and  
2           diameter of the first member ranges from about 2200 to 2500 microns  
3           and 15 to 25 microns.

1           94. The mirror assembly of claim 91, wherein the length and  
2           diameter of the second member ranges from about 800 to 1000  
3           microns and 8 to 15 microns.

1           95. The mirror assembly of claim 73, wherein each T-shaped hinge  
2           provides a torsional spring.

1           96. The mirror assembly of claim 95, wherein the spring constant  
2           ranges from about 2x10<sup>-7</sup> to 10x10<sup>-8</sup> lbf/radian.

1           97. The mirror assembly of claim 73, wherein one or more of the  
2           T-shaped hinges include:  
3                 a first member; and  
4                 a second member coupled to the first member;  
5                 wherein the second member is perpendicular to the first  
6                 member.

1           98. The mirror assembly of claim 73, wherein one or more of the  
2           T-shaped hinges include:  
3                 a first member; and  
4                 a second member coupled to the first member;  
5                 wherein the second member is serpentine.

1           99. The mirror assembly of claim 73, wherein one or more of the  
2           T-shaped hinges include:  
3                   a first member; and  
4                   a second member coupled to the first member; wherein the  
5                   second member is offset from the center of the first member.

1           100. The mirror assembly of claim 73, wherein one or more of the  
2           T-shaped hinges include:  
3                   a first member; and  
4                   a second member coupled to the first member; wherein the  
5                   second member intersects the first member at an acute angle.

1           101. An apparatus, comprising:  
2                   a housing;  
3                   a mass; and  
4                   one or more springs for coupling the mass to the housing, each  
5                   spring including:  
6                       a rotational spring constant; and  
7                       a translational spring constant;  
8                   wherein the rotational spring constant is decoupled from the  
9                   translational spring constant.

1           102. The apparatus of claim 101, wherein the springs are fabricated  
2           by a process including micro-machining a substrate.

1           103. The apparatus of claim 101, wherein the housing, mass and  
2           springs are fabricated by a process including micro-machining a  
3           substrate.

1           104. The apparatus of claim 101, wherein each spring comprises a  
2           plurality of springs.

1           105. The apparatus of claim 101, wherein each spring is T-shaped.

1           106. The apparatus of claim 101, further including:  
2                 a top cap coupled to the top of the housing including a top cap  
3                 cutout; and  
4                 a bottom cap coupled to the bottom of the housing including a  
5                 bottom cap cutout;  
6                 wherein the top and bottom cap cutouts limit movement of the  
7                 mass when the mass is rotated away from its rest position.

1           107. The apparatus of claim 106, wherein each cutout includes  
2                 tapered side walls.

1           108. The apparatus of claim 107, wherein the tapered side walls are  
2                 rotated from the vertical direction at an angle ranging from about 15 to  
3                 45 degrees.

1 109. A method of resiliently supporting a mass in a housing,  
2 comprising:  
3       coupling the mass to the housing using one or more springs  
4       having translational spring constants and rotational spring  
5       constants; and  
6       decoupling the translational spring constants from the rotational  
7       spring constants.

1 110. The method of claim 109, wherein the springs are fabricated by  
2 a process including micro-machining a substrate.

1 111. The method of claim 109, wherein the housing, mass and  
2 springs are fabricated by a process including micromachining a  
3 substrate.

1 112. The method of claim 109, wherein each spring comprises a  
2 plurality of springs.

1 113. The method of claim 109, wherein each spring is T-shaped.

1 114. The method of claim 109, further including:  
2 limiting movement of the mass when it is rotated from a rest position.

1           115. The method of claim 114, wherein limiting movement of the  
2           mass when it is rotated from a rest position includes limiting translation  
3           of the mass when it is rotated from the rest position.

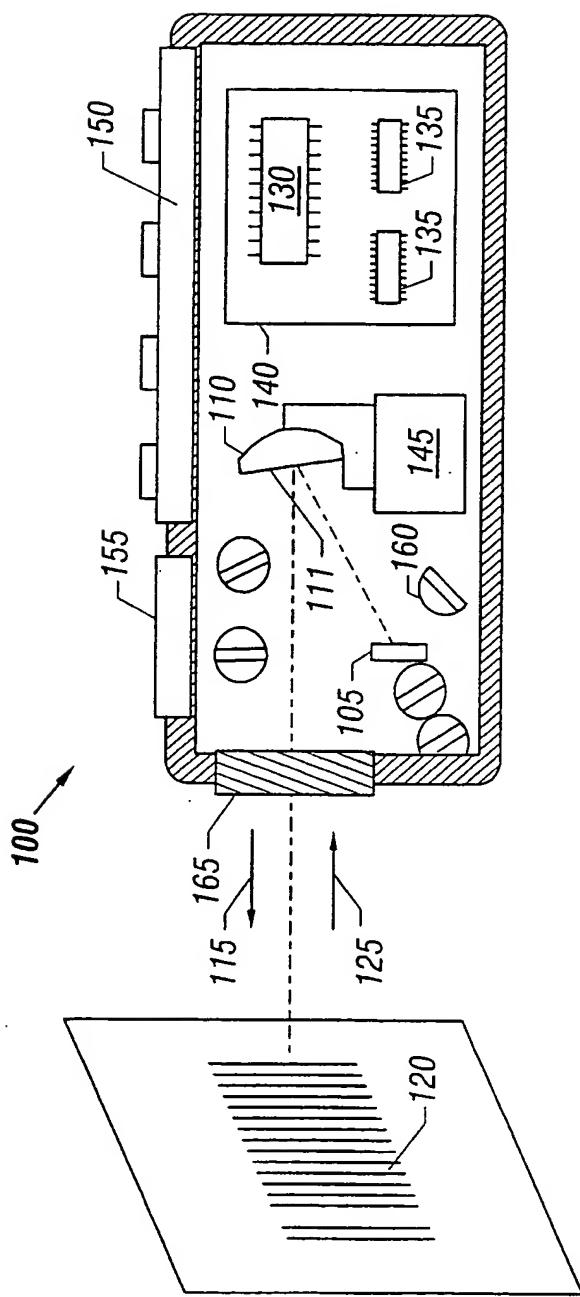


FIG. 1

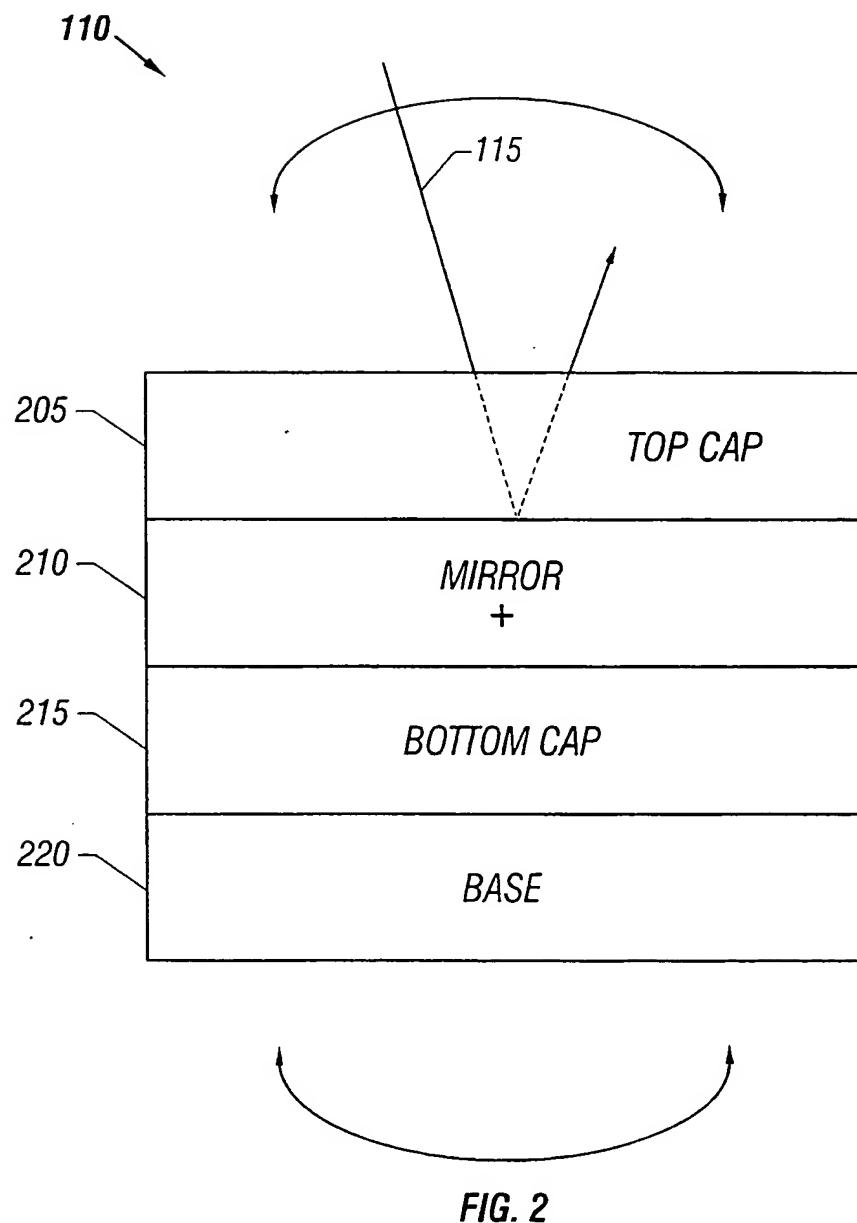


FIG. 2

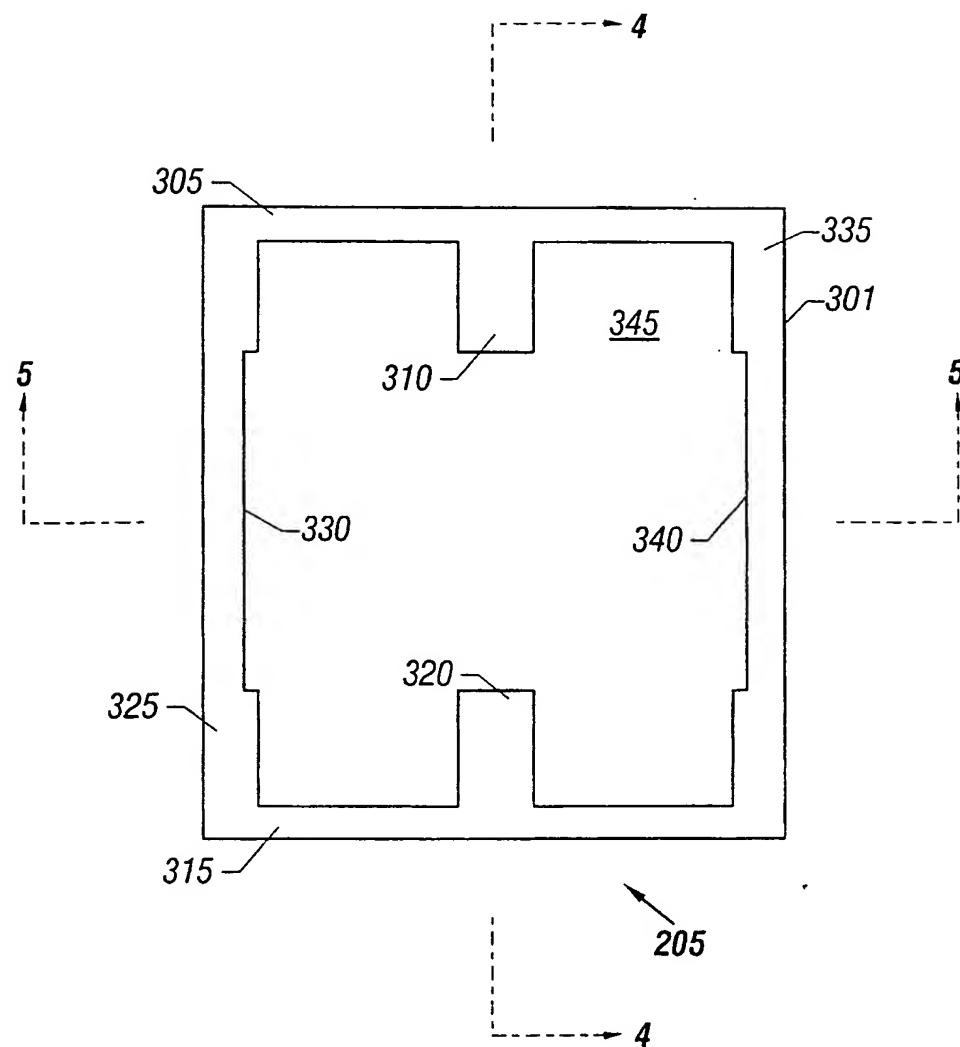


FIG. 3

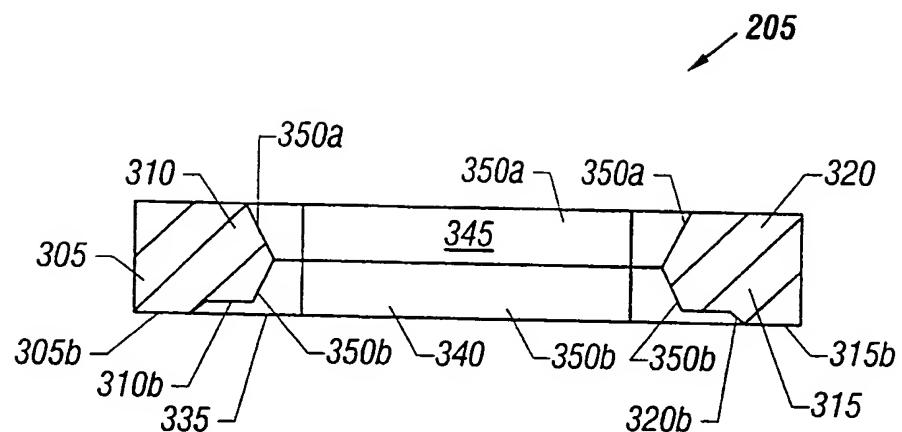


FIG. 4

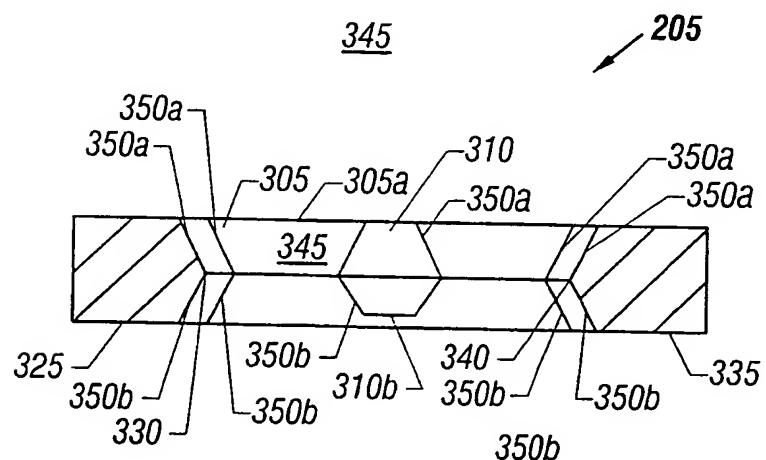


FIG. 5

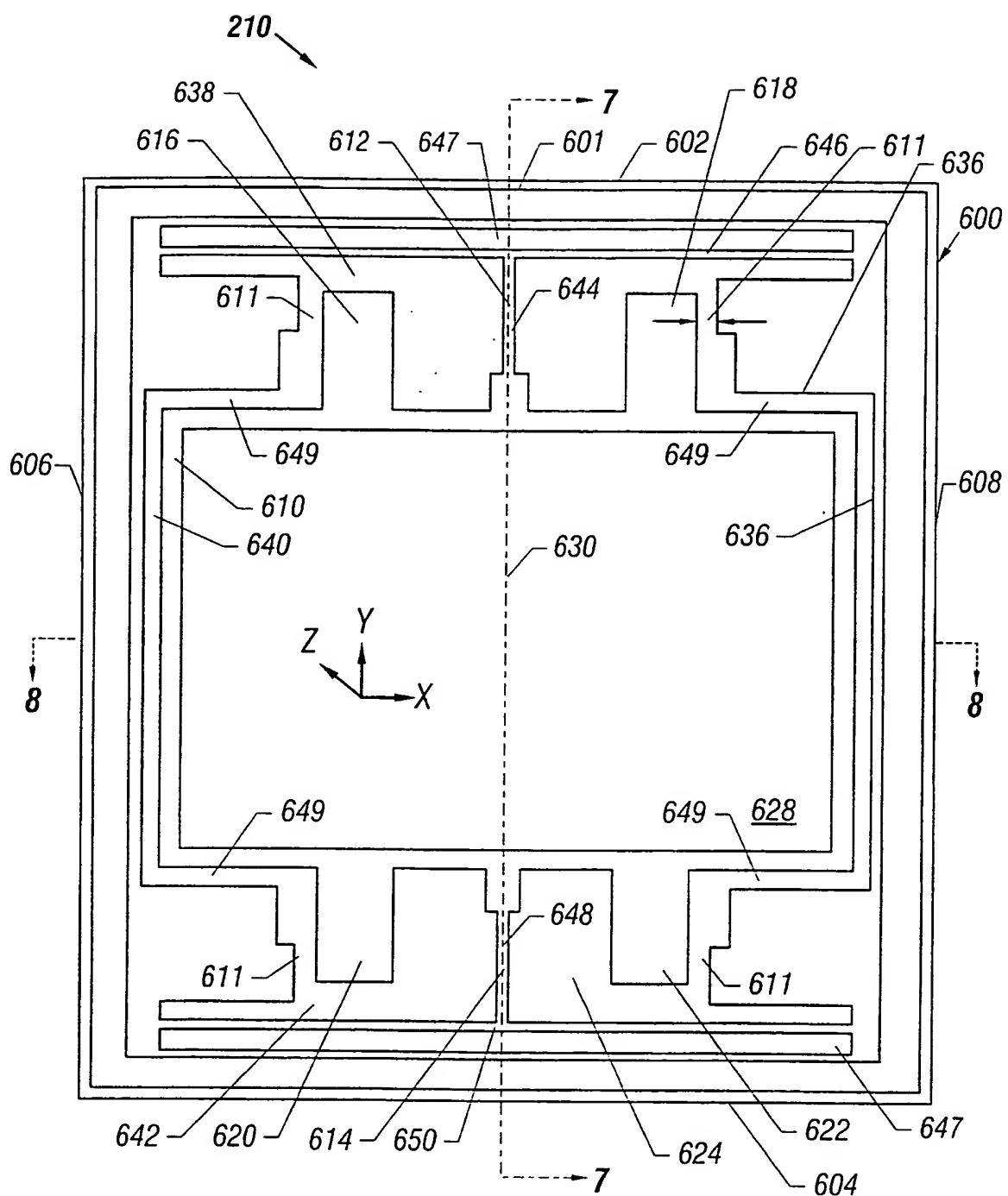


FIG. 6

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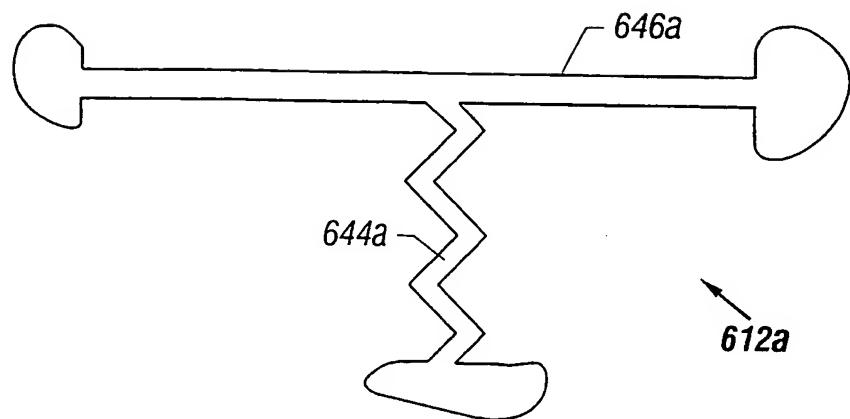


FIG. 6A

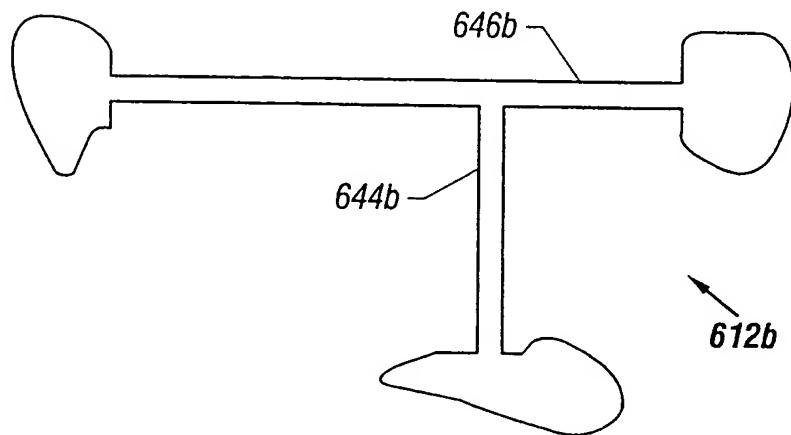


FIG. 6B

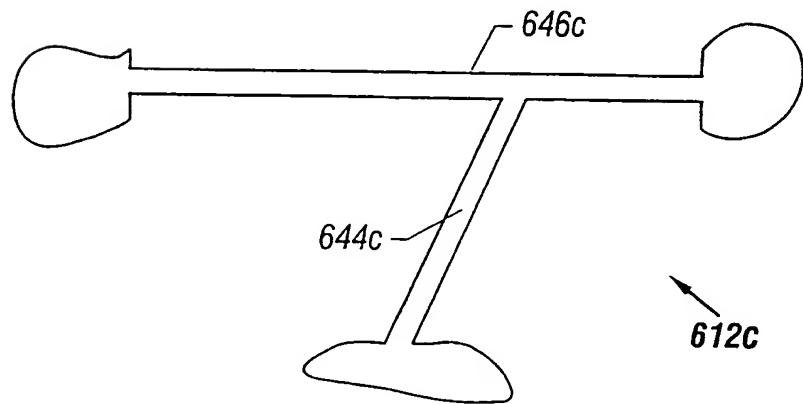


FIG. 6C

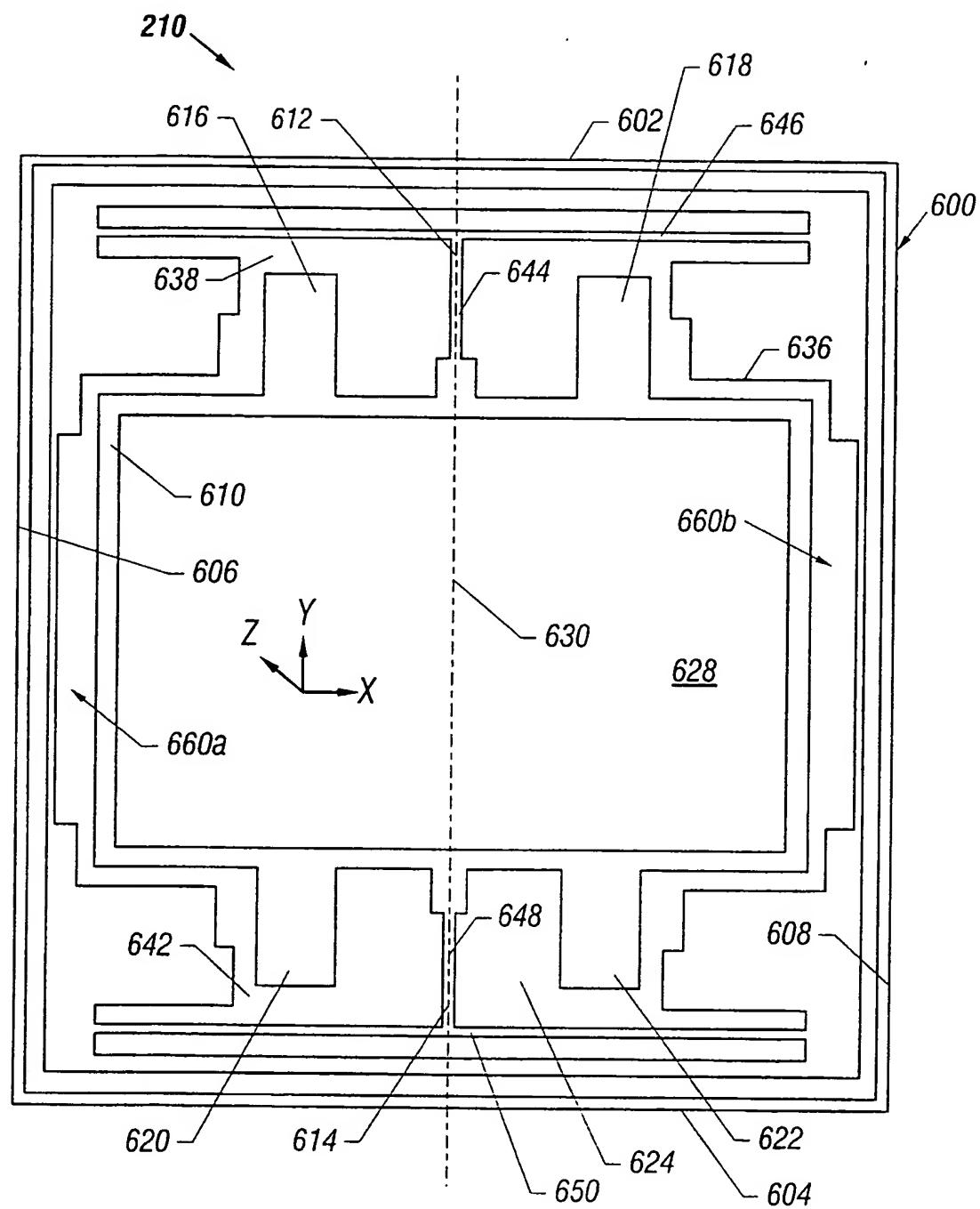


FIG. 6D

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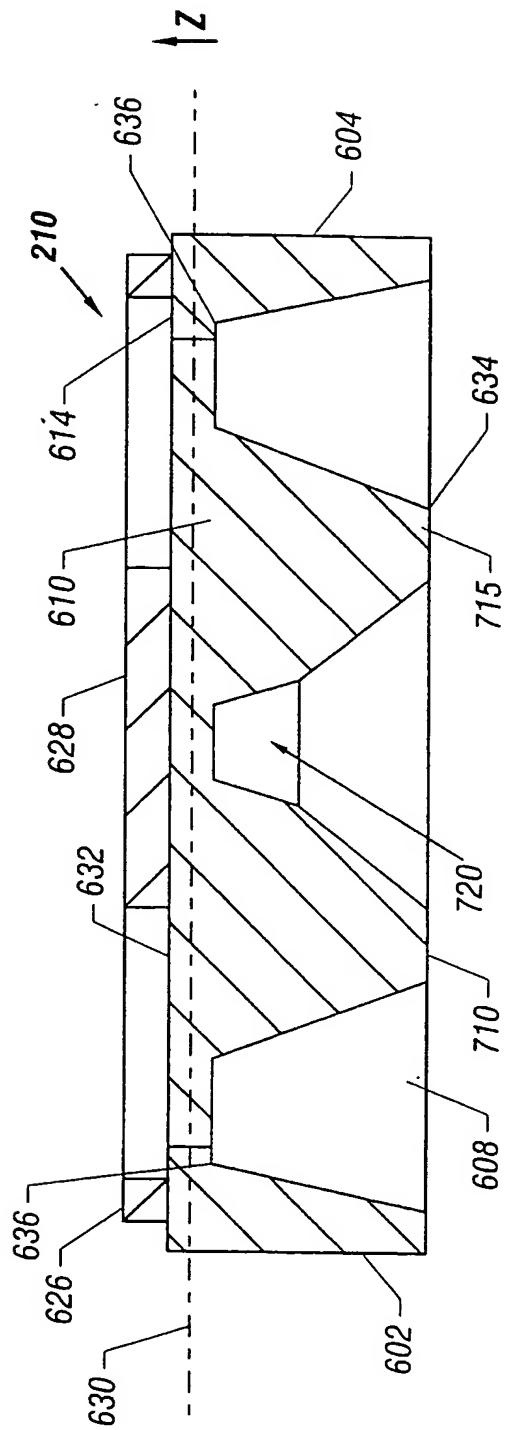
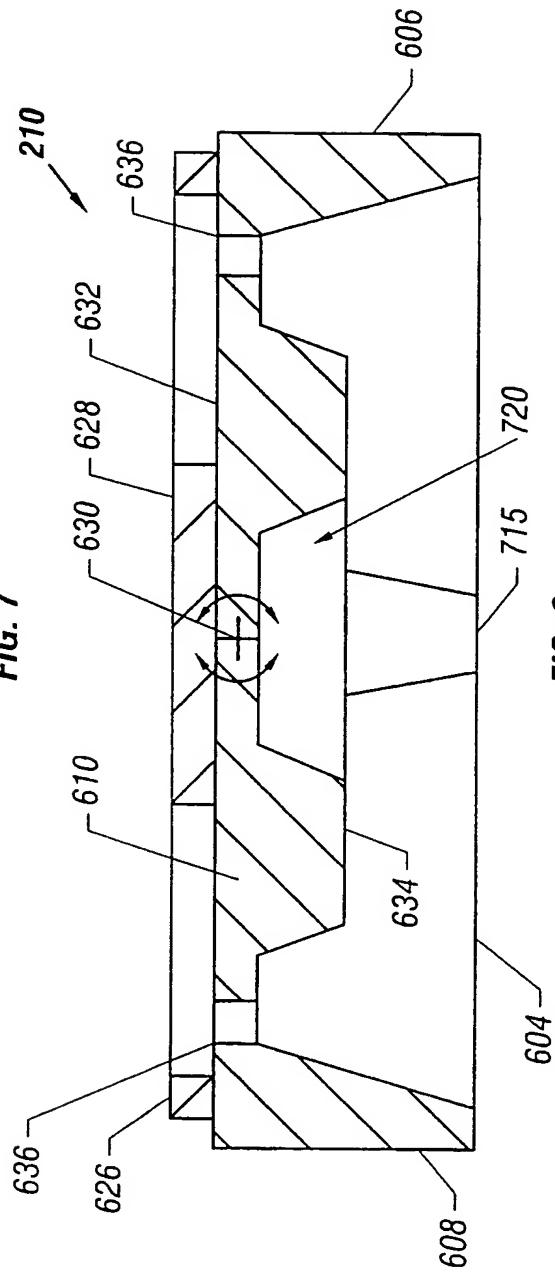


FIG. 7



8  
FIG.

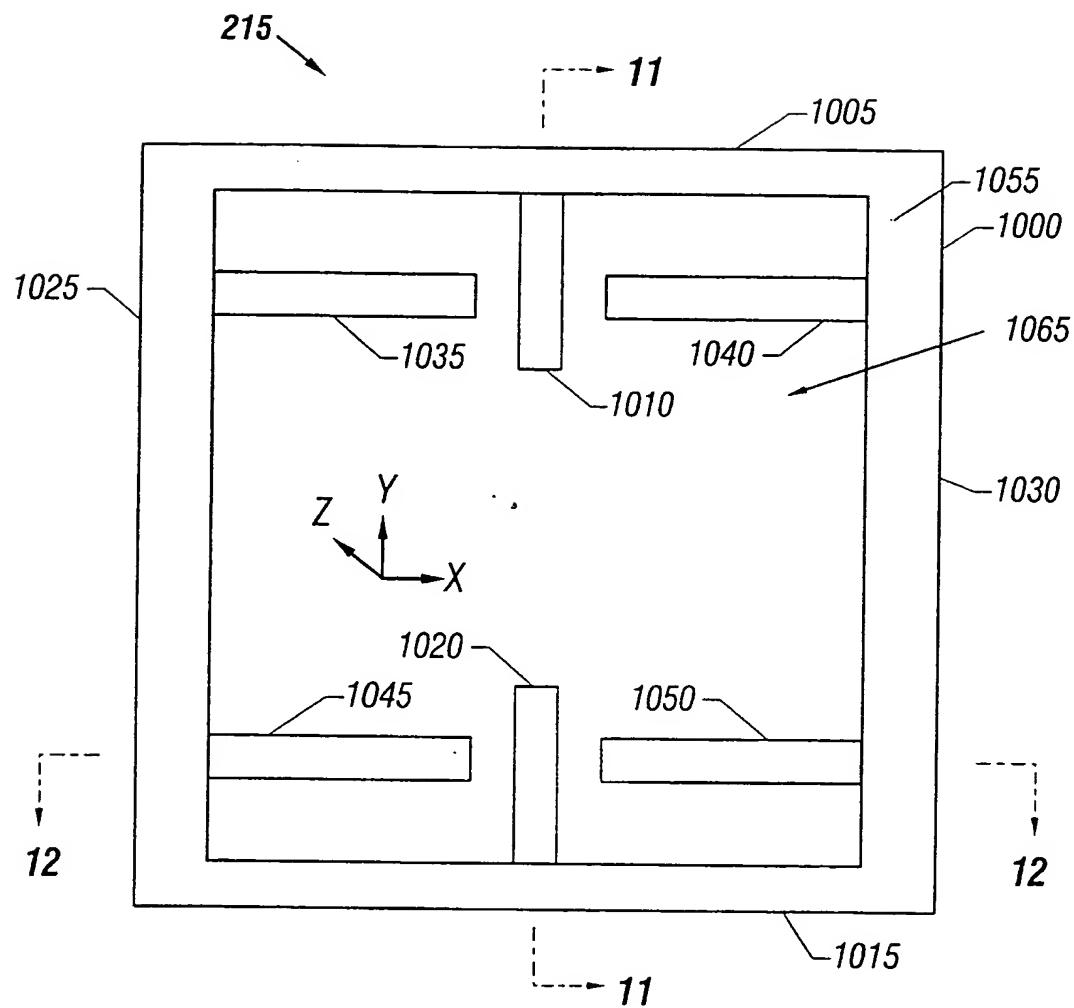


FIG. 10

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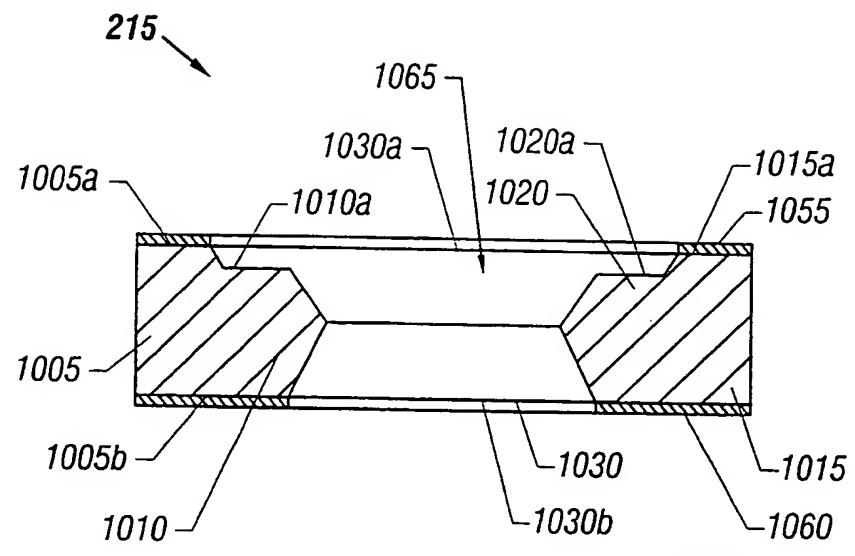


FIG. 11

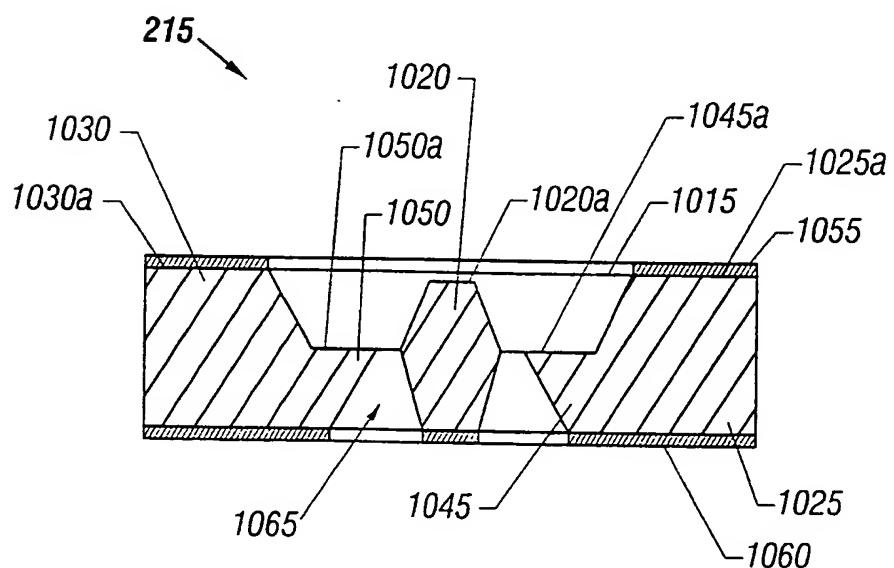


FIG. 12

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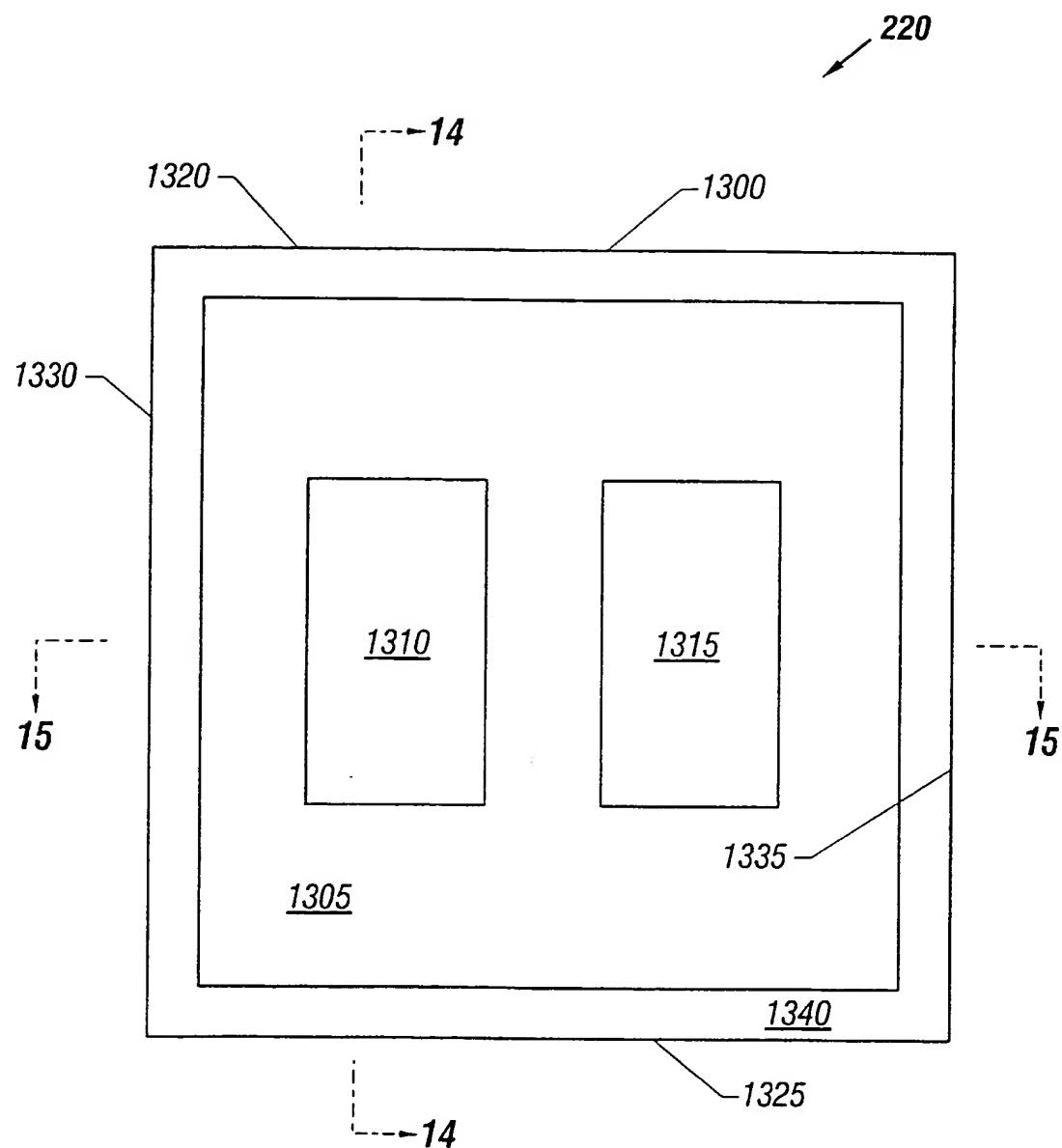


FIG. 13

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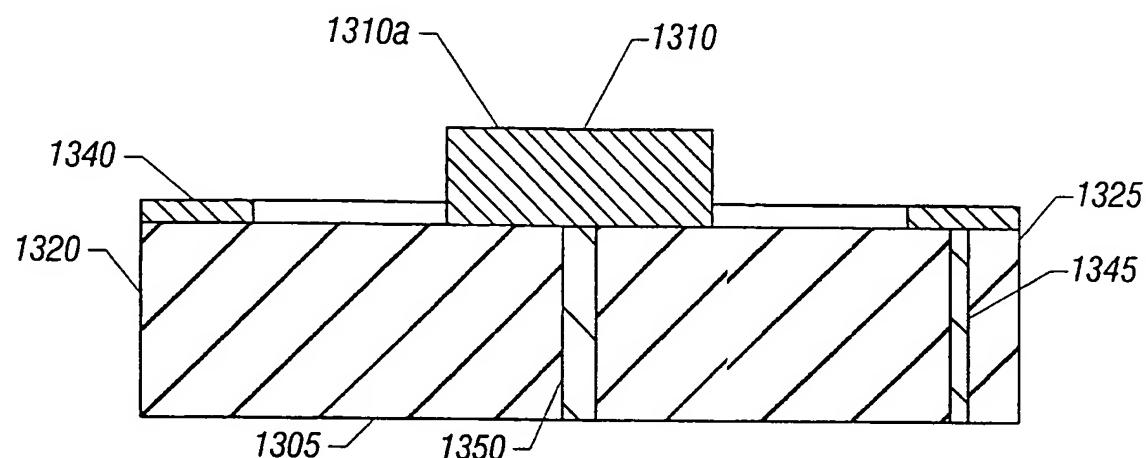


FIG. 14

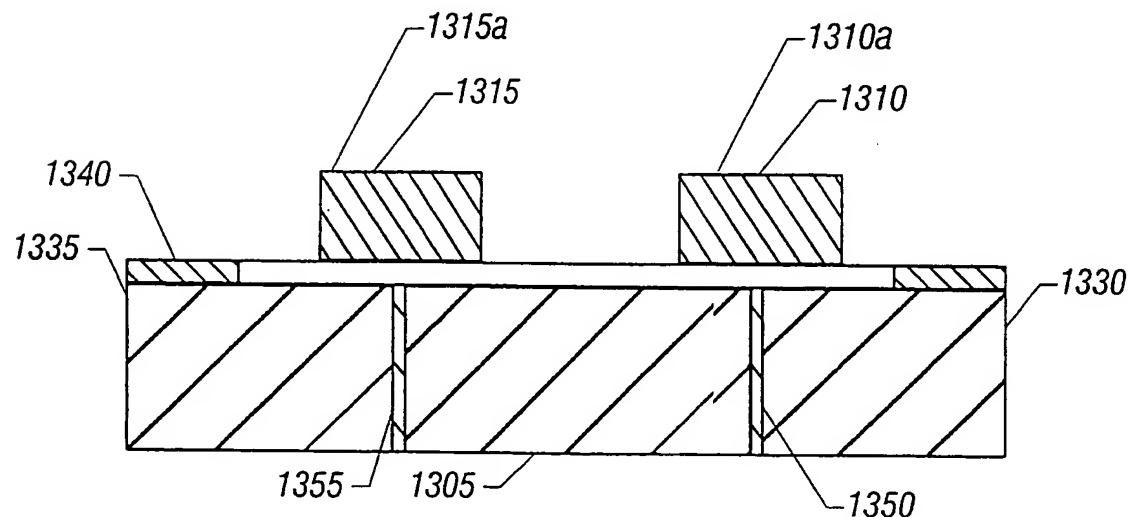


FIG. 15

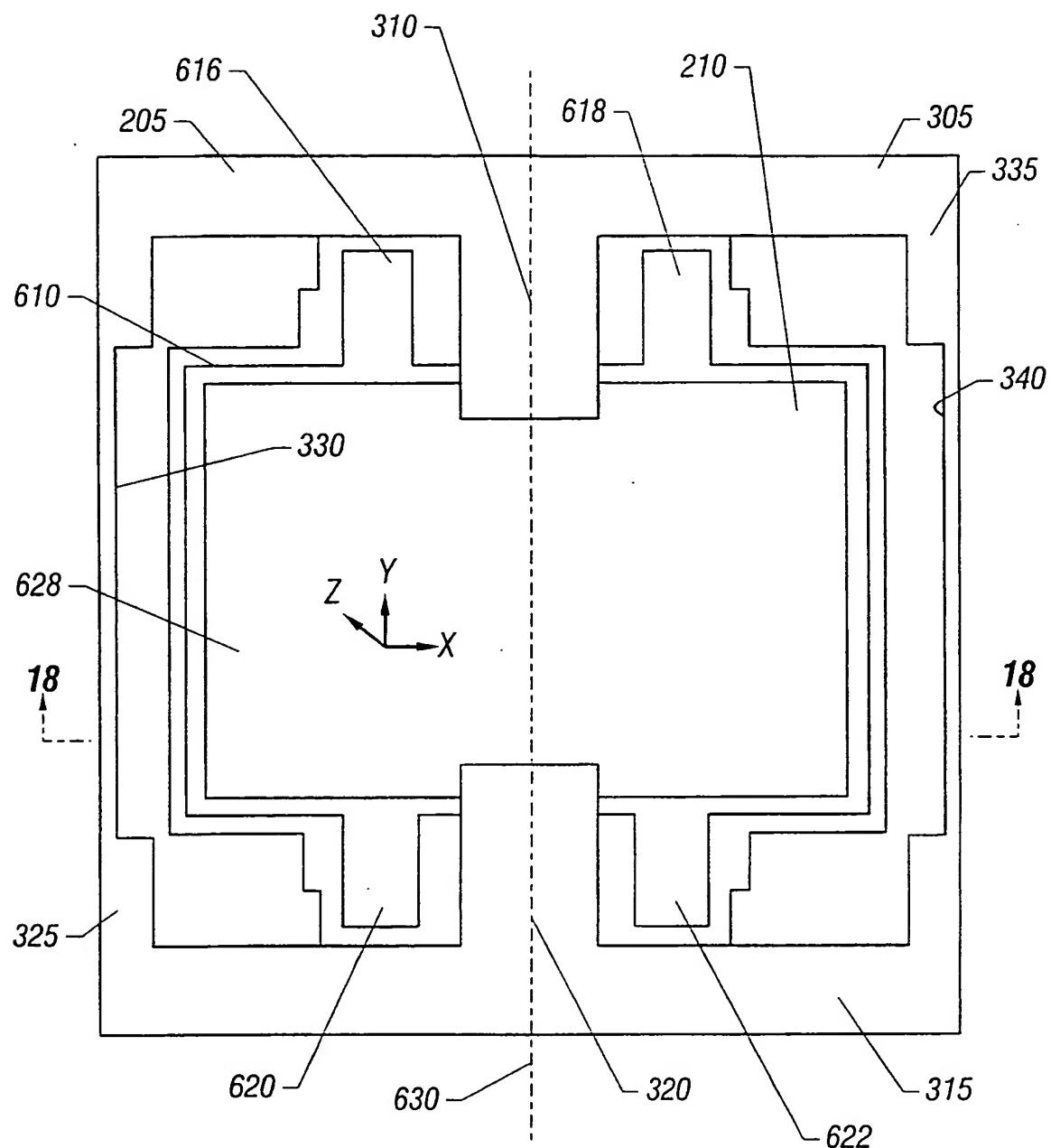


FIG. 16

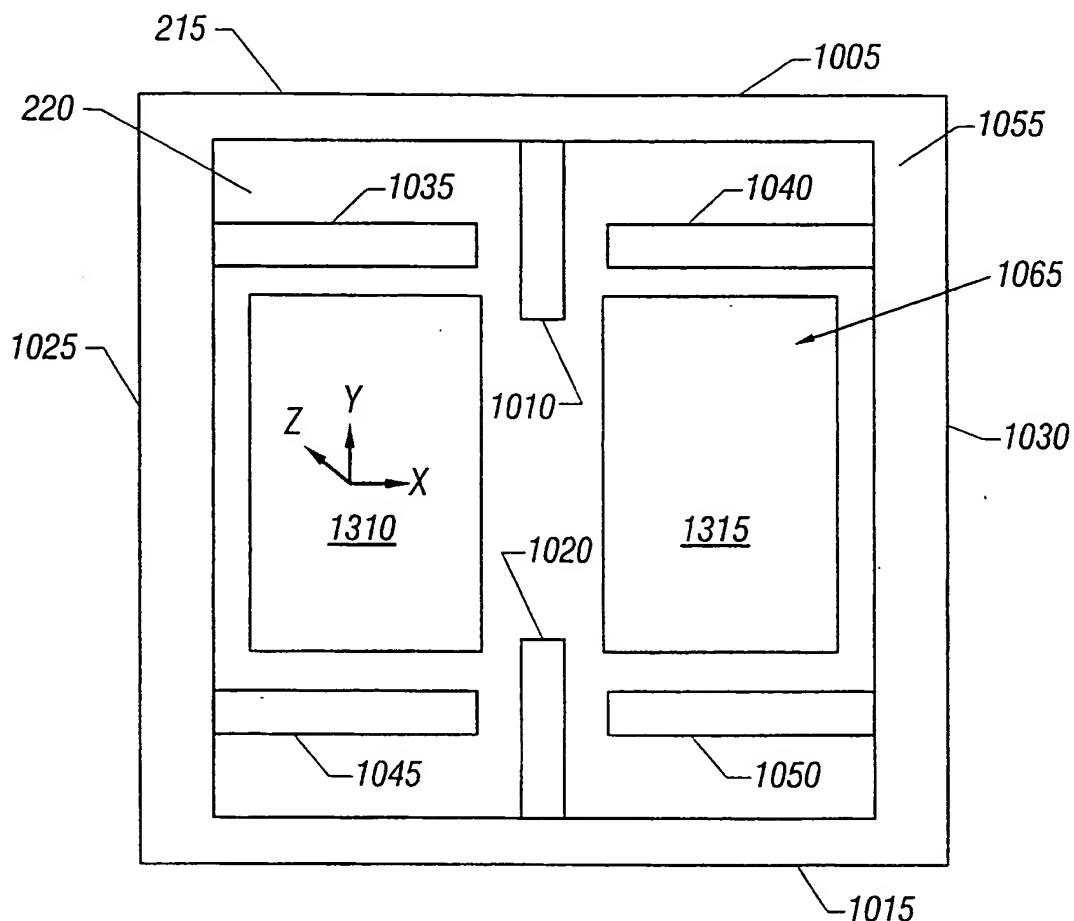


FIG. 17

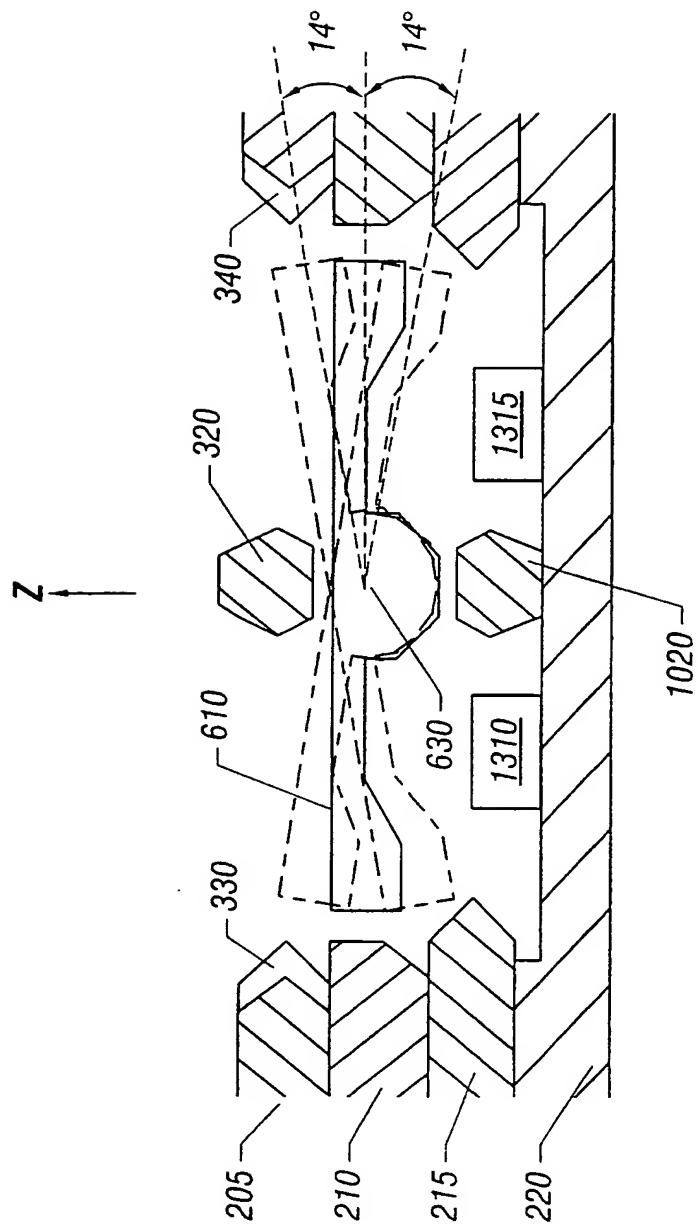


FIG. 18

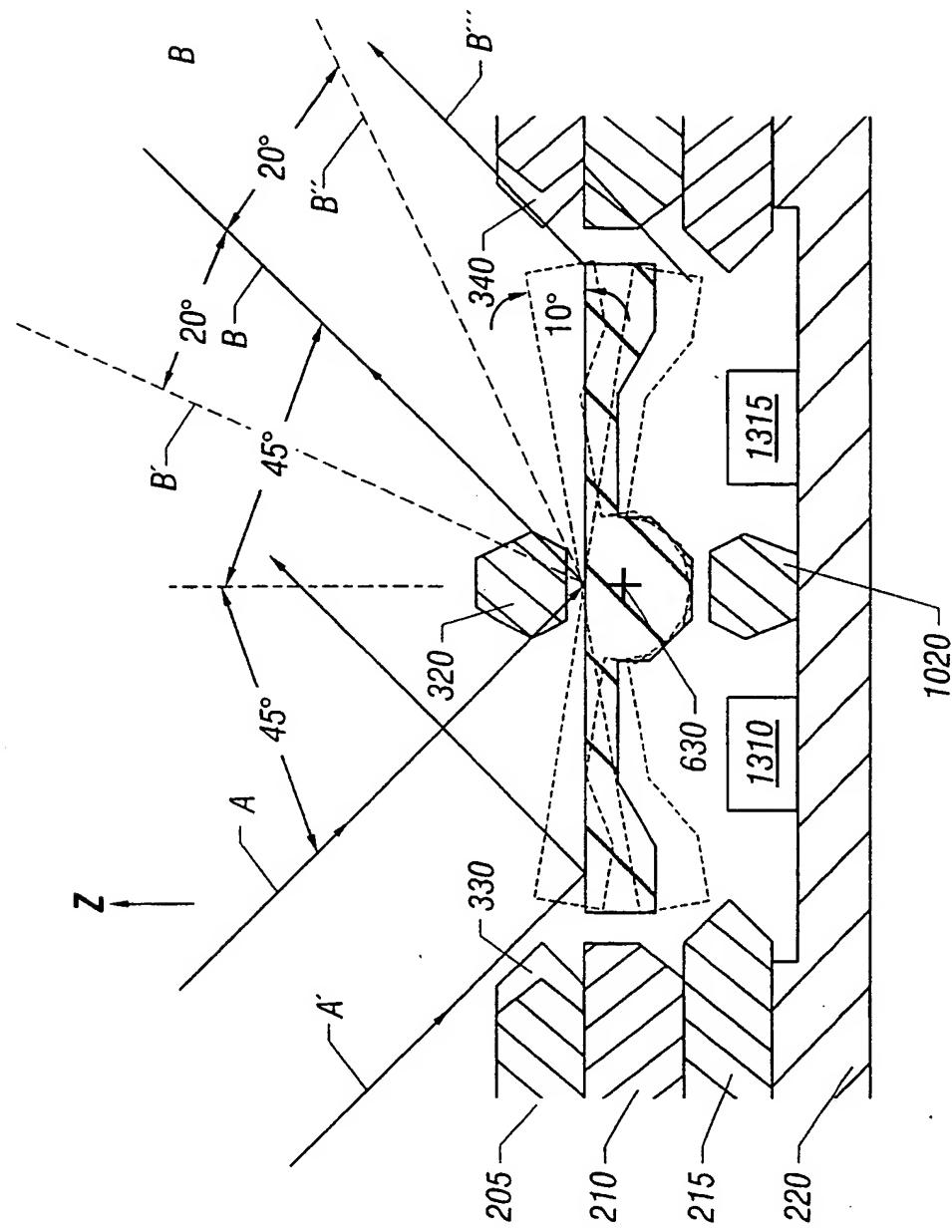


FIG. 19

## INTERNATIONAL SEARCH REPORT

International application No. PCT/US00/18998
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## A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :G02B 7/182

US CL :359/871

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 359/871, 872, 224; 248/466

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

BRS

search terms: micro machined, hinge, spring

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A,P	US 5,999,303 A (DRAKE) 07 December 1999 (07.12.1999), see entire document.	1-115

Further documents are listed in the continuation of Box C.  See patent family annex.

• Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
*A* document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
*E* earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
*L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
*O* document referring to an oral disclosure, use, exhibition or other means		
*P* document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search  31 AUGUST 2000	Date of mailing of the international search report  14 SEP 2000
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Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer  MARK ROBINSON Telephone No. (703) 305-3506 <i>Karen Preston</i>
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